The TREND
IN ENGINEERING

at the University of Washington

In this issue:

OSCILLATOR RESPONSES TO EARTHQUAKE MOTIONS

A SIMPLE METHOD OF APPLYING ELECTRIC STRAIN GAGES TO CONCRETE REINFORCING BARS

A MICROWAVE FIELD DETECTOR

INVESTIGATION OF FLOW THROUGH AN OPEN CHANNEL WITH SCREEN BED

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WHAT PRICE CREATIVITY?

INDUSTRY AND EDUCATORS have apparently convinced the public that American prestige and progress in technology depend on "creativity" and their ability to turn out more "creations" and "creators." Management is briefed on how to become "creative"; educators are advised to prime the pump by means of "creative questions." Sweeping generalizations about creativity, often based on insufficient data, have followed this indiscriminate usage. The fact is that studies of human behavior are approached with great caution by experts in the field, because evidence to support almost any stand can be produced. Let us outline briefly some distinctions, and then examine several widely publicized claims.

"Creativity" can be considered either as a general characteristic of man which definitely sets him apart from the lower orders or, in its highest form, as a special gift manifested in great works of art, science, invention, and philosophy. In the former sense it is a universal quality to be nourished as the source of one of the deepest satisfactions known to man and a bulwark to his feeling of personal worth and dignity. In the latter sense it applies to the productions of genius. Between the two are innumerable levels, ranging from a child's finger-painting to Einstein's theories. We should, then, limit the frame of reference within which we are setting up this term.

Creative Thinking and Genius

The process of creative thinking, which is generally the same in any field of thought, involves four stages: preparation, incubation, illumination, and verification. These terms have become familiar to our ears. But we must realize that the complete process takes place only if the problem is sufficiently difficult to prevent its solution by simple associative means or a short reasoning process. John R. Pierce, of the Bell Telephone Company, writes that technological innovation does *not* mean "the tail fins on this year's automobile, nor a new catch on a refrigerator door. A true innovation must perform some important function."[1]

Two conditions contribute to successful creative thinking. First, the thinker must not be coerced. Howard E. Fritz, research head of the B. F. Goodrich Company, is quoted as saying, "Inspiration is and can be the product only of free men." Dr. Max E. Bretschger noted that the German chemists, supposed to be the most creative, under the Nazi whip permitted the United States to outthink them.[2] Time limits set by employers in which to produce research results are a form of coercion. The high-level creative thinker works under a stern, but self-imposed, discipline.

Second, "emotion is the ferment without which no creation is possible."[3] Creative thinking thrives on enthusiasm. Motivations may differ widely, but creations of value do not seem to be the product of "cold reasoning," alone.

Here is the machinery. Who are the generators? In the operation of creativity are many levels. Since industry, government, and educational institutions agree that the pressing need is for more "top-level" scientists, let us start with "genius." William James defined it as "an electric aptitude for analogy."

Characteristics of a genius often cited are "drive," self-confidence (in his own field), strength of character, and "wholeness of vision." Most geniuses refuse to conform to set patterns of thinking and conventional behavior. They usually possess another personal quality less easily defined than illustrated. Many examples at first- and second-hand could be quoted, but two will suffice.

"Einstein put down his ideas like a medium in a trance who listens to the voice of a higher power. . . . The most conspicuous feature of Einstein's personality . . . was its completely visionary character."[4]

William J. Kroll, speaking of the individual inventor, said, "Very often a secret hand guides him to his goal."[5]

This mystic attribute, perplexing to the average engineer and entirely outside industry's usual personnel patterns, complicates the question: How can we make the best use of our geniuses today?

Group Research and Genius

The very qualities which contribute to genius are likely to unfit the top scientist or technologist for successful group work based on the idea of the cooperative "team." He is impatient with colleagues who cannot keep up with his pace; he is, let us admit, often arrogant in defending his ideas. And, finally, he just doesn't like the setup! Here are a few opinions.

Alexander Fleming (discoverer of penicillin): "A team is fine when you have something to go on, but when you have nothing to go on—well, I should think a team is the worst possible way of starting."[6]

Dr. Kroll, on accepting the 52nd Perkin Medal: "Lone wolf researchers, invaluable in our way of life, must be given asylum and protection from the extinction threatening their kind from the growth and spread of teamwork in the industrialized atmosphere of America."[5]

Norbert Wiener: "The great laboratory may do many important things at its best, but at its worst it is a morass which engulfs the abilities of the leaders as much as those of the followers."[7]

Arthur Compton: "It is not possible for anyone to tell a scientist what he must do, for his proper course of action is determined by the facts as he finds them for himself."[8]

Lee de Forest in his autobiography said that he found it difficult to work under conditions short of complete autonomy.

A few industries are exceptional in providing research conditions favorable to individual creativity. The Arthur D. Little Company, believing that "the process of creative thinking is generally the same in any field of thought," set up their plan for "using men of exceptional inventive talent as a loosely coordinated group." They brought in William J. J. Gordon "inventor, student of psychology and the arts" and, in addition, "an automotive inventor, a machinist, a marine biologist, an anthropologist and a chemist turned sculptor." All have a "certain manual dexterity" and work in a shop that is "small, messy and full of 60-year-old 'clunkers' with which members of the group can try to prove their inventions."[9]

In the General Electric Laboratories, Coolidge, Langmuir, and Steinmetz were given great freedom to work individually and to follow their own interests.[10] We might note that these men were already famous when they were so engaged and that only the most powerful and profitable industries can afford such laissez-faire research.

The Bell Telephone Company is notable for research whose practical application may be long deferred and for encouraging individual inventiveness. The men, for instance, "whose studies led to the development of the transistor were not a closely organized and firmly directed 'team'; they were talented individuals working on matters of great personal as well as mutual interest."[1]

But this intelligent group use of the genius or highly inventive man can accommodate only a small number of such men engaged in industrial research. Others, creatively

endowed but less favorably placed, may be trying to smooth off the square corners that distinguish them, the better to fit into their round holes. The more promising, in the eyes of industry, may be members of research teams.

Invention and Development

Specific reports of the success of "brainstorming" techniques and, indeed, of most of the procedures to induce and increase creativity in the research team, seem to concern problems dealing less with invention than with development. One new invention may open up innumerable possibilities for development, so that organized team work and "deliberate creativeness" directed into appropriate channels may be the most efficient (and profitable) means of carrying on mass research. But does the fact that this work is often on a lower creative level change entirely the conditions under which the individuals on each team can realize their creative potentials and contribute most effectively to production? True, closer organization, training in problem-solving techniques, more attention to individual motivations will be required. These men may have had little creative development in their earlier years.

However, recourse to judicious use of "the whip," "needling" applied to the exact individual tolerance, and "sugaring-up" by the sort of bribery used to make children conform to social laws, are poor techniques. No evidence shows that engineers are so easily taken in; indeed, their reactions to management seem to prove the contrary. While the mediocre and fearful may submit, the most talented may rebel, and the results will be poor. Industry must recognize that efficiency and creativity are served by opposite means and that the best balance must be sought.

Research Productivity

Unfounded sweeping statements have been mentioned. Take, for example, the claim that tests of group versus individual research showed 65% to 93% more "free associations" from group ideation than from individual results.[2] Although such a purely quantitative estimate is of no value for our purpose, similar tests leading to different conclusions can be cited. Dr. Donald W. Taylor, Professor of Personnel Administration at Yale, concludes that group discussion cuts down on the number of ideas and lowers the chances of getting original and good ones. For example, one experiment in which 96 students tried to solve three problems in "brainstorming" groups proved more unsuccessful than where individuals worked alone.[11]

Another author asserts that "it is almost axiomatic that a properly selective research committee can be more effective creatively than the sum of the creativeness of the same persons acting individually."[12] This statement hangs on the undefined word, "effective."

Some of these comparisons are based on the number of patents issued to the group and the sum of patents of the individuals comprising the group. Measuring, much less evaluating, results of group and individual research by the number of patents is not valid. "The relevance of patent statistics to what is really happening in the field of invention is very obscure." Among reasons listed for this assertion are the following: (1) all inventions are not patented, (2) patents cover inventions of enormously varying importance, (3) corporations may take out patents for strategic purposes, and (4) distinguishing individual from corporation patents is impossible, because of patent assignments.[10]

Quantitative calculation of creative values is reminiscent of Kettering's story about the head of a firm who, on being told a certain research project would require six men and two years' time, gave instructions to hire 12 men for one year.[10]

O. A. Ohman, Director of Organization Planning of the Standard Oil Company (Ohio) admits that "when it comes to true innovation . . . the record of the big corporations is not impressive."[13] Many industrial research teams have been notably successful, but a study of 61 outstanding inventions since 1900, all of which have been or promise to be commercially successful, disclosed 33 to be products of individual inventors.[10]

The Industrial Laboratory

The advantage of elaborate and expensive equipment afforded by industrial laboratories is often cited as a major factor in research production. While true in many cases, especially in the final development of a process involving construction of a pilot plant, it does not invariably apply. In the invention of the cyclotron, television, most of the important textile inventions, Kodachrome, and many others, the original equipment used by the inventors was cheap and often makeshift.[10] In fact some geniuses stress the disadvantage of ready-made equipment to the exploring inventor. The Arthur D. Little Company recognized the fact that the inventor's thinking often finds expression in manual dexterity applied to simple but ingeniously contrived devices.

One author urges that "the trend toward more and more complex apparatus should be carefully watched and controlled; otherwise the scientists themselves gradually become specialist machine minders."[14] Dr. Kroll asserted that "many laboratories . . . are overgadgeteered and drowned in complicated equipment which it frequently takes more time to fix than to use. These instruments remove the searcher from his experiment."[5]

Specialization

Specialization in the field concerned is usually assumed to be indispensable for successful creative thinking. Again, notable exceptions, especially in invention, can be cited. While the findings of most researchers are the outcome of prolonged intensive study of their subjects, successful inventions are not invariably the products of specialists. Gillette (safety razor) was a traveling salesman in bottle caps; Eastman (photography) was a bookkeeper; Godowsky and Mannes (Kodachrome) were student musicians; Dunlop (pneumatic tire) was a veterinary surgeon; Carlson (xerography) was a patent lawyer. An undertaker invented the automatic telephone dialing system, and a newspaperman the parking meter.[10]

In fact, Bessemer stated, "I find that persons wholly unconnected with any particular business have their minds so free . . . to view things as they are . . . that they are the men who eventually produce the great changes."[15]

The Human Variable

It has been said that environment cannot produce genius but it can destroy it. High-level creativity is not likely to flourish under rigid processing imposed by management, no matter how impressively the system is described, nor how alluring the bait. Training programs should have as one major objective the "spotting" of a potential genius—possibly by his refusal to be properly trained. Dr. Kroll asserted that if Steinmetz applied today for a job in industry he would be turned away as an impossible eccentric. But suppose that, as a young unknown, he were hired? *How long would he willingly remain?*

Sighting the Goal

Industry gets the genius or highly talented man at the age when he should be well on his way to top achievement.

(Continued on page 17)

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CONTENTS

What Price Creativity? 1

Oscillator Responses to Earthquake Motions: A New Approach to the Lateral Force Problem *Frank Neumann* 5

A Simple Method of Applying Electric Strain Gages to Concrete Reinforcing Bars *George G. Goble* . 11

Investigation of Flow Through an Open Channel with Screen Bed *Ling-Sheng Miao* 14

A Microwave Field Detector *T. G. Williams, A. E. Harrison* 18

Publications and Graduate Theses College of Engineering 1957-1958 20

Engineering Research Dividends 26

Elastic Instability of Kinked Axes Columns *F. C. Pneuman*

Gas to Particle Heat Transfer in a Fluidized Bed *D. E. Orgen*

Subject Index Volumes 9-10 27

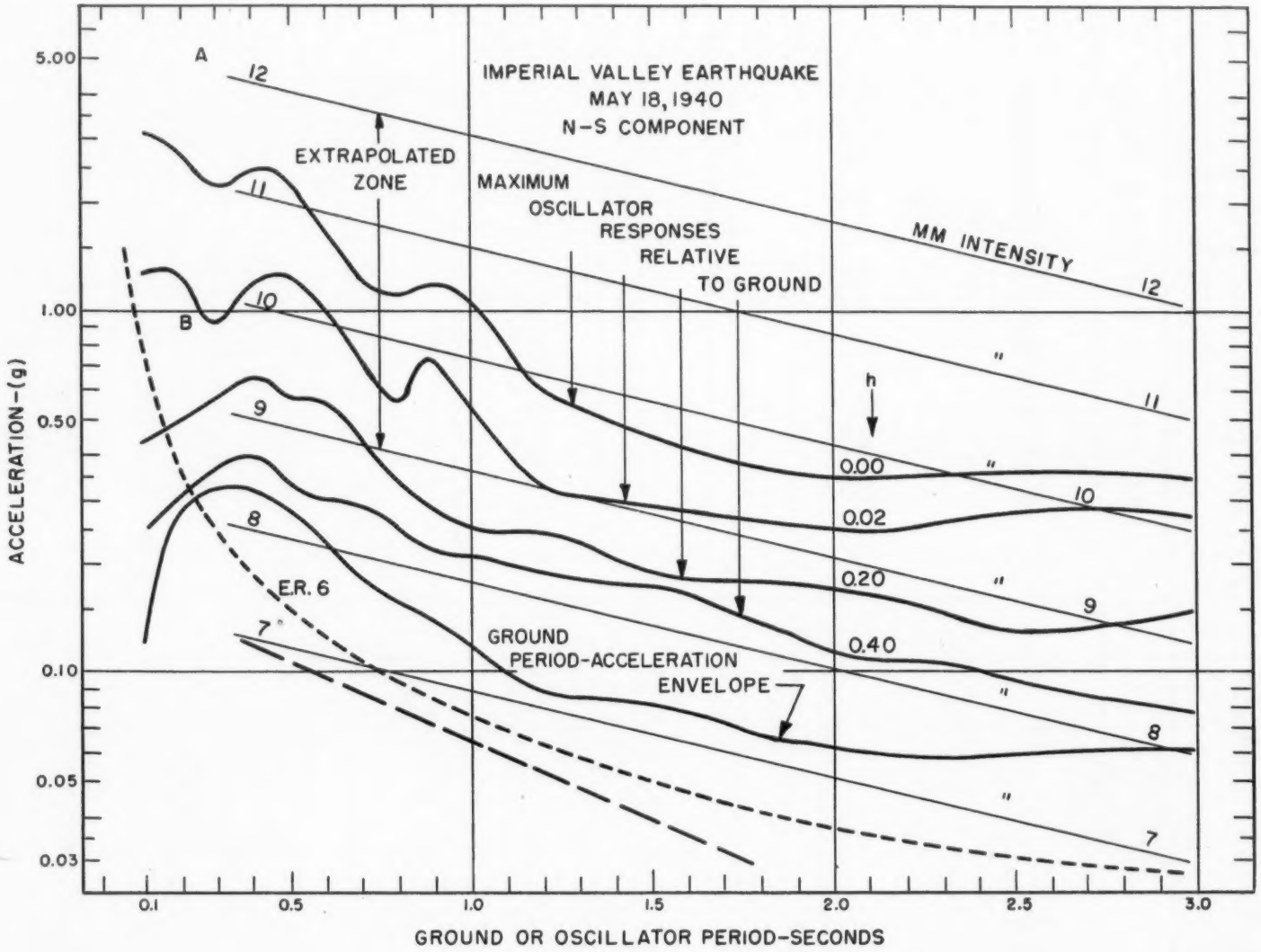

FIG. 1. PROVISIONAL QUANTITATIVE INTENSITY GRID

OSCILLATOR RESPONSES TO EARTHQUAKE MOTIONS

A New Approach to the Lateral Force Problem

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Frank Neumann

Introduction

The problem of earthquake-resistant design requires that the research engineer first obtain some basic information on ground and building movements during strong earthquakes, that he correlate these data insofar as possible with the theoretical response of oscillating systems to forced vibrations, and from these studies finally develop some kind of formula or procedure that will enable him to estimate or predict earthquake stresses in specific structures. Whether or not this has been even partially accomplished is still a debatable question.

In this paper we shall be concerned only with deformations due to relative motion between the center of oscillation of an oscillator, or building, and the moving ground.* Because of the complexity of earthquake vibrations and the wide variety of ground-motion patterns registered on seismographs, the building phase of the problem is simplified by using mechanical oscillators to simulate fundamental building responses. When the simple oscillator problem is solved one may then consider the more complex types of building reactions to ground vibrations.

All buildings experience elastic deformation during an earthquake. The magnitude of the deformation depends primarily on the natural vibration period of the building and the amount of internal friction generally referred to as damping. When a simple oscillator is used to simulate the motion of a building one envisions a concentrated mass fixed to the top of a flat vertical spring and its lower end fixed to the ground or some base that follows the motion of the ground. Such an oscillator used in laboratory tests or theoretical studies must also be subjected to various degrees of damping. Assuming that an oscillator has the natural period and damping of a real or hypothetical building, the oscillator mass will theoretically simulate the motion of the center of oscillation of the building if both are subjected to the same complex earthquake motions. Once the maximum oscillator deflection (or its maximum acceleration) relative to the moving ground is known, it is then the engineer's problem to determine the over-all type of deformation that a given structure will experience. It may be in the nature of a shear (for low buildings), a flexure (for tall buildings), or a combination of both. From the maximum effective oscillator acceleration one may evaluate the overturning moment impressed on a structure or assume under certain conditions that it is a measure of base shear. Even after the oscillator problem is solved the engineer still faces formidable problems in correlating theoretical oscillator performance with actual building motion.

To solve the oscillator response problem one requires seismograph records of strong and destructive earthquake motions, and some information on how oscillators of various periods and damping react to such motions. Instrumental records of strong earthquakes are available from the U.S. Coast and Geodetic Survey which, since 1932, has operated a network of strong-motion stations to aid in solving this problem. (See bibliography.) The theoretical maximum responses of series of multiperiod oscillators under various conditions of damping have been computed for a limited number of instrumentally recorded earthquake motions by the Earthquake Research Laboratory of the California Institute of Technology. The curves that summarize the results of these computations are called earthquake spectra. The expressions, "earthquake spectra" and "maximum oscillator responses," may be used interchangeably. Figure 1 shows four modified maximum oscillator response curves that were computed by the Research Laboratory. It is necessary to understand the true nature and special characteristics of earthquake spectra in order to understand their application to the lateral force problem.

Earthquake Spectra

When a spectrum is said to show the maximum responses of a series of multiperiod oscillators to a particular earthquake motion, it means the maximum

* Intensities and damage related to absolute accelerations were discussed in the writer's paper, "Damaging Earthquake and Blast Vibrations," in the January, 1958, issue of *The Trend in Engineering*. These two papers complement each other and explain why the seismic force that throws over a bookcase is not the same force that causes structural deformation in the building housing the bookcase.

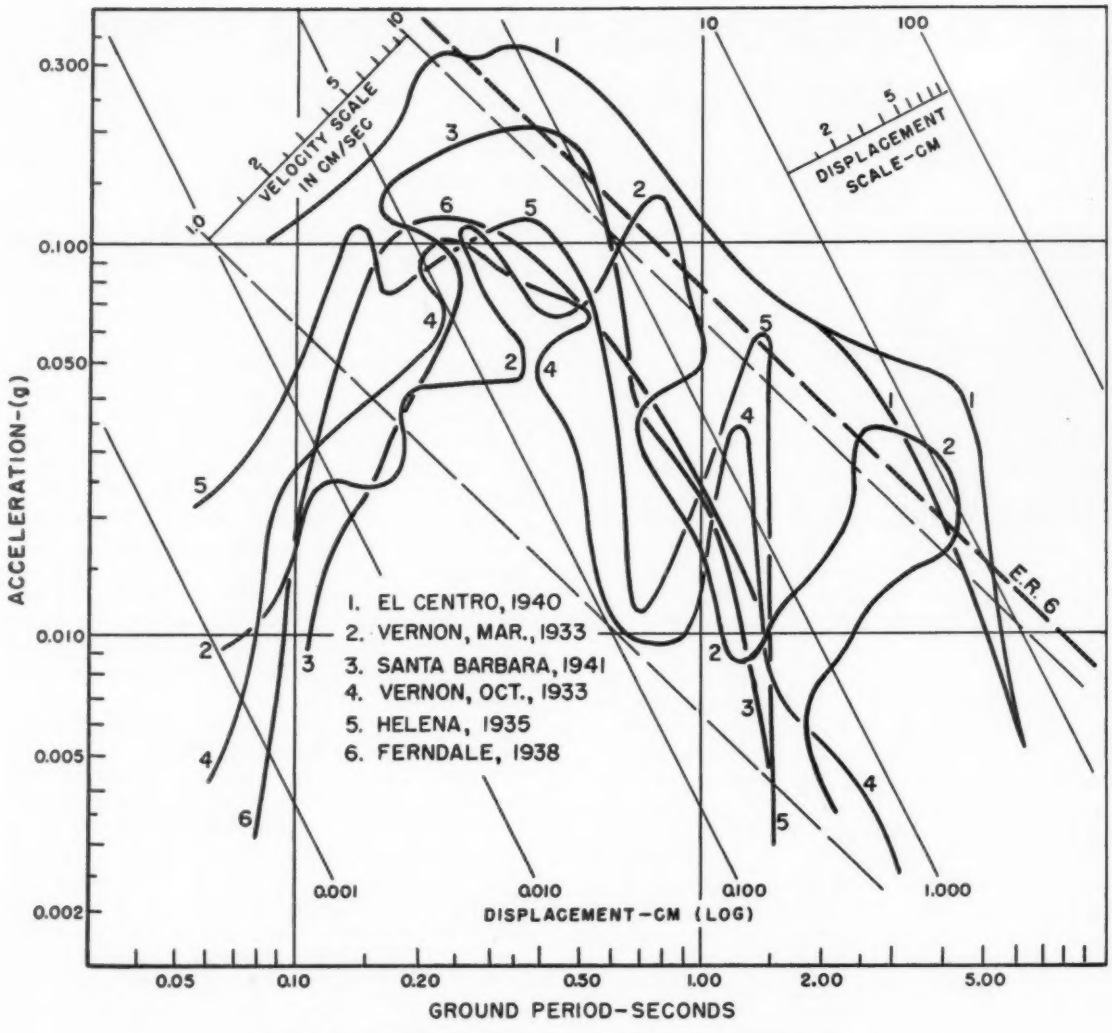

FIG. 2. PERIOD-ACCELERATION ENVELOPES FOR SIX EARTHQUAKES

response of each oscillator *relative to the moving ground beneath it.* It is the relative displacement that measures the deformation of a building. This maximum relative displacement and the acceleration and velocity associated with it are functions of the period and damping of the oscillator. The acceleration that would produce this maximum relative displacement of a particular oscillator is obtained simply by multiplying the displacement by $4\pi^2/T^2$ where T is the oscillator period. A static acceleration of this magnitude, such as a component of gravity, could produce the same oscillator deflection. For this reason spectrum accelerations are frequently referred to as yielding equivalent static forces.

The form of the equation used by D. E. Hudson for computing oscillator responses to complex ground motions is

$$\ddot{x} = \frac{2\pi}{T}\int_0^t \ddot{y}(\tau)e^{\frac{-2\pi n}{T}(t-\tau)}\sin\frac{2\pi}{T}(t-\tau)d\tau\,,$$

in which $\ddot{x}$ is the desired effective oscillator acceleration at any instant, $\ddot{y}$ is the ground acceleration at that instant, n the oscillator damping, T the oscillator period, t the time, and τ a time parameter. In the rest of this paper the symbol h is used instead of n.

Since the processing of a single accelerograph record yields only one point on a spectrum, i.e., the computed maximum velocity of the oscillator (integrating an acceleration-time curve yields velocity), the task of computing spectral values for many oscillators for several degrees of damping from even one earthquake record becomes a prodigious and costly one. Various methods have been proposed, but to date the great majority of such computations have been made on an electrical analog computer at the California Institute of Technology.

If the problem is simplified to cover only oscillator motions due to a steady-state SHM ground vibration of constant amplitude and an arbitrarily chosen period, one obtains a set of response curves that is familiar to all branches of science in which the theory of forced vibrations plays a part. In seismology these so-called sustained SHM magnification curves are used to compute ground amplitudes from seismograph records on the assumption that the vibration is a steady-state one, but these same curves can also be considered earthquake spectra for the simple hypothetical type of ground motion just mentioned. The oscillator response is a function of the ratio between ground and oscillator periods. If the ground period and amplitude are held constant while the pendulum (or oscillator) periods vary, the curves are analogous to earthquake spectra. A set of such curves appeared in the author's paper, "Damaging Earthquake and Blast Vibrations."[1]

Quantitative Earthquake Intensity Grid

Before discussing earthquake spectra further, a new tool employed in this paper to analyse these spectra will be briefly described, namely the Provisional Quantitative Earthquake Intensity Grid. This is a grid discussed in the writer's booklet, *Earthquake Intensity and Related Ground Motion,* which aims to show the maximum acceleration to be expected in an earthquake of any intensity for any ground period that may be present in the earthquake motion. Figure 1 shows the nature of the grid which is a first effort to establish such a relationship between earthquake intensity and ground motion on an entirely empirical basis.

The grid was developed by correlating the period-acceleration envelopes derived from important acceleration records with the intensities experienced at the places where the records were obtained. One such envelope is shown in Fig. 1. Each grid line may be considered an envelope for all period-acceleration envelopes representing ground motions associated with the grid line intensity. The intensity lines in Fig. 1 show the period-acceleration distribution in most of the earthquake records studied, but some deviations occurred, presumably due to differences in regional geology, such as that indicated by the broken line branching off from the start of the intensity 7 line. This points up the fact that no single grid can be representative of the period-acceleration distribution in all earthquakes.

Another feature of the grid is that the over-all form is valid only for epicentral areas. As epicentral distances increase, the high-frequency waves no longer are the maximum acceleration waves.

In "Damaging Earthquake and Blast Vibrations," the writer pointed out that over a very wide range of ground periods a particular intensity which is identified by the onset of potentially damaging vibrations (Crandell's E.R.6) is always closely related to the maximum vibrational velocity. The writer interprets this as the maximum velocity of either a building or ground vibration. Figure 2 shows how this velocity function is related to certain earthquake data that can be read in terms of acceleration, velocity, or displacement on a four-way logarithmic grid. One can see in Fig. 2 a rather well-defined correlation between velocity and the dominant wave periods found in some of the strongest earthquakes thus far registered. The E.R.6 function is drawn again in Fig. 1 for comparison with the grid lines previously discussed because both are intended to show the various period and acceleration combinations that may be associated with a given intensity. Perhaps we should be more concerned with the single reading of maximum velocity found in each earthquake record than with the form of the period-acceleration distribution in that record which may change with regional geology. Both, however, are of engineering interest. It seems that in the maximum vibrational velocity found in any earthquake record we may have an acceptable measure of intensity that is independent of period and adaptable to frequencies far higher than those found in earthquakes. This should be verified, however, by further investigation.

It will be seen in Fig. 1 that, even if maximum velocity were ultimately found to be the best measure of intensity, the provisional grid lines (based on period-acceleration envelopes) would not differ greatly from those of a velocity grid if the periods were limited to those found in the earthquakes thus far studied. For this reason it is believed that the provisional grid may still be used for analytical purposes if the foregoing reservations are kept in mind, and with the understanding that further research is required to mold the grid into a reliable engineering tool.

The intensity lines on the grid represent correlations between observed earthquake effects and instrumentally recorded ground motions only through intensity 8. Above that the grid represents a pure

[1] *The Trend in Engineering,* January, 1958.

extrapolation. It is not known how much the actual recording of an intensity 12 shock will agree or disagree with the accelerations shown. This, however, should not invalidate the use of the grid for measuring spectrum intensities because the primary interest is in the comparison of spectrum accelerations, not in how well these accelerations agree with a particular grade of intensity.

Oscillator and Ground Periods

The arguments used on the original intensity grid (period vs. acceleration) are similar to those used on earthquake spectrum curves. On the grid the period refers to ground periods. On earthquake spectra, however, it refers to periods of the oscillators used in computing the spectra. A spectrum, as Fig. 1 shows, is obviously a measure of the over-all intensity of the motion impressed on the oscillators, and a period-acceleration envelope is likewise a measure of the over-all intensity of the motion of the ground, or the motion impressed on the ground by extraneous earthquake forces. The question therefore arises: What is the real significance of a ground period? The writer contends that, when the ground vibrates as a result of vibrations in the basement rock and when the basement rock and other formations are forced into vibration by earthquake waves traversing them, the response of the ground (represented by the period-acceleration envelope) is as much an earthquake spectrum as one obtained by computing the responses of a series of mechanical oscillators. Basins of alluvium have natural periods of their own, and the various layers that constitute the earth's crust also have natural periods depending upon their elastic constants and dimensions. Internal friction must also give these geological oscillators various degrees of damping. The period-acceleration envelope derived from an earthquake record shows the maximum responses of all these oscillators.

One may reasonably ask: How can a period-acceleration envelope which represents certain aspects of a ground motion or a combination of ground motions be considered analogous to the maximum (relative) accelerations of a series of oscillators when the envelope represents only the motion of a point beneath the seismograph? Both represent oscillator motions; it is only the method of measuring these motions that is different. So far as the period and amplitude of each mechanical oscillator is concerned, their measurement is automatic and direct. A period-acceleration envelope, on the other hand, furnishes the same type of information but the period and amplitude of each geological oscillator must be read from a seismograph record. The ground beneath the seismograph responds to the motions that geological oscillators of various periods and amplitudes impress upon it from time to time during the progress of the earthquake, and this is what the seismograph registers. Waves of different period are often superimposed on one another. If the mechanical oscillators that produce earthquake spectra were overdamped to the point where there would be little or no relative motion between oscillator and ground, the oscillator spectrum would approach zero as a limit. The geological spectrum, or period-acceleration envelope, on the other hand, cannot be subjected to such arbitrary changes. It is simply an observational fact. One is free to compare it in magnitude with earthquake spectra which show the maximum motions of oscillators relative to the ground, or with maximum absolute motions such as might be registered by instruments on the various floors of a building.

This basic similarity between geological and mechanical oscillator responses justifies transferring earthquake spectrum curves to the intensity grid for evaluation of their over-all intensity. This in no way hinders using the mechanical spectra to serve the same purpose that they normally serve, that is, to determine the maximum acceleration impressed on an oscillator of given period and damping by a given earthquake motion. The technique here to be proposed for evaluating the lateral forces on oscillators due to earthquakes of various intensity is based on this concept.

The Grid as a Tool for Measuring Spectrum Intensities

The bottom curve in Fig. 1 is the period-acceleration envelope derived from the east-west acceleration record obtained at El Centro, California, at the time of the shock of May 18, 1940. The maximum intensity 8.3 is obtained by ascertaining the highest point on the curve with reference to the diagonal intensity lines and reading the exact intensity by interpolating, linearly, between intensity lines 8 and 9. In other earthquakes such a point of maximum intensity as 8.3, might occur at some other ground period, in which case the acceleration also would change. If the period of an intensity 8.3 earthquake were 2.0 seconds the corresponding acceleration would be 0.13 g.

The curves drawn successively above the ground curve are earthquake spectra computed from the above-named record in which the oscillator damping values are successively $h = 0.4$, 0.2, 0.02 and 0.00. Damping is critical when h is unity. For the top spectrum ($h = 0.0$) only the average values of the extreme excursions of the oscillators are plotted. Points A and B indicate the maximum range of these undamped oscillator motions. It will be noted that the periods associated with the points of maximum intensity are not always the same for pendulums having different damping factors but, broadly speaking,

the oscillator spectra follow the general form of the ground spectrum.

If similar ground and oscillator spectra are drawn for other earthquake motions, the periods associated with the maximum intensities will vary over a wide range but the same broad pattern of similarity will exist between ground and oscillator spectra. Figure 2 shows the wide variety of form found in period-acceleration envelopes. The earthquake spectra computed from the same seismograph data may be expected to vary in the same degree in their over-all patterns. Figure 2 also shows that the waves of highest acceleration are not the only important ones; longer period waves of much lower acceleration may possess the same amount of energy. All points above and to the right of the E.R.6 line are provisionally considered to indicate potentially damaging vibrations. In view of all these facts it would seem quite unwise, as some have suggested, to attempt to create a typical or representative type of spectrum that would adequately serve the purpose of the structural engineer.

Figure 2 should also be carefully scrutinized by anyone who may wish to interpret earthquake vibrations as a series of random impulses without regard to certain observational facts. Virtually all earthquake vibrations registered to date can be associated with particular periods or combinations of periods, and it should be obvious that all of these waves are limited in amplitude by the energy associated with the intensity of the earthquake. The wave period is the only random feature about an earthquake or blast vibration and this is controlled in large measure by regional geological features. The writer feels that serious misconceptions can be introduced into engineering seismology research either by assuming fictitious motions or not adhering closely to observed wave forms in various analytical procedures. So far as random periods are concerned the writer believes that the concept of envelopes as exemplified in the quantitative intensity grid adequately takes care of the problem.

A most significant point about an intensity grid is that the intensity lines serve as envelopes for all spectra associated with the same intensity of motion, regardless of whether they are pendulum or ground motions. This can be accepted as an experimental fact or it may be considered a logical result of the argument that period-acceleration envelopes and earthquake spectra are fundamentally analogous methods of measuring maximum oscillator responses. A given intensity line on the grid represents the limit of all period-acceleration combinations that are possible in an earthquake or in oscillator motions of equivalent intensity. Any point on such a line, therefore, indicates either the maximum relative acceleration of an oscillator having the period indicated by its position on the grid, or the maximum acceleration of the ground associated with that particular ground period.

From Fig. 1 the intensities corresponding to (1) the ground motion and (2) the four modified oscillator motions representing the various degrees of damping previously stated are successively 8.4, 8.7, 9.3, 10.3, and 11.4. This means that, for the pertinent damping values of $h = 0.4$, 0.2, 0.02, and 0.0, the increases in oscillator motion intensities over those of the ground are successively 0.3, 0.9, 1.9, and 3.0. If the damping were high enough the spectrum intensity could be less than that indicated by the ground period-acceleration envelope. Applying this same type of analysis to a limited number of other available period-acceleration envelopes, the following average increases in intensity are found to be associated with the degrees of oscillator damping just specified:

Damping (h):	0.4	0.2	0.1	0.2	0.00
Intensity increase:	0.5	1.0	1.3	2.0	3.0±

This relationship is shown graphically in Fig. 3.

The intensity increase for different shocks may vary 0.2 or 0.3 of an intensity grade from the average increases here quoted. It is thus feasible to establish a relationship between the over-all amplitude of earthquake spectra and period-acceleration envelopes of the corresponding ground motion if it is done through the medium of an intensity grid. Since for the same period each grade increase in intensity corresponds to a doubling of the displacement or acceleration, the preceding five intensity increases mean that the effective oscillator accelerations are respectively increased (approximately) by the factors 0.4, 2.0, 2.5, 4.0 and 8.0± over and above the maximum ground accelerations.

Determination of Maximum Lateral Force

The foregoing discussions and results lead to the following procedure for determining the maximum lateral acceleration exerted on an oscillator of known period and damping when subjected to an earthquake motion of given intensity. Suppose the oscillator period is 1.7 sec, damping, h, is 0.2, and intensity is 7 on the MM scale. If h is 0.2, the increase in intensity of the oscillator motion over that of the ground is 1.0 (Fig. 3), making the intensity of the oscillator motion 8.0. From the intensity grid the *maximum* possible acceleration that can be impressed on an oscillator of 1.7-sec period during any intensity 8 disturbance is 120 cm/sec², or 0.12 g.

Using the same type of lateral force computation in the case of the Hollywood Storage Building at the time of the October 2, 1933, earthquake, the method can be checked by an accelerograph record which

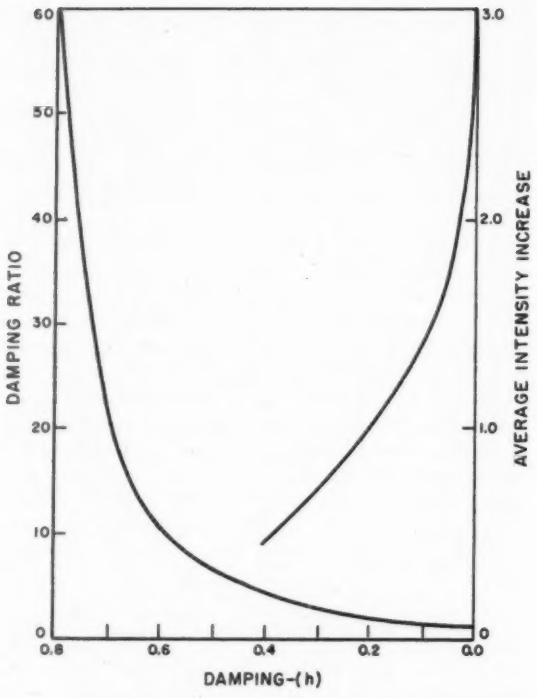

FIG. 3. RELATIONSHIP OF DAMPING RATIO TO AVERAGE INTENSITY INCREASE

was obtained at the time in the penthouse. The intensity in Hollywood based on descriptive reports was 5. The intensity evaluation based on an analysis of the basement record was 5.3. The damping ratio of the building determined by M. P. White and others in 1941 was 1.2:1 which, in terms of h, is equivalent to 0.058. Using this damping factor, an increase in oscillator intensity over ground intensity of 1.5 can be expected. This adds up to intensity 6.5 for the spectral intensity. The period of the Hollywood Storage Building in the direction under consideration is 0.50 sec. On the intensity grid an oscillator of this period at intensity 6.5 experiences a maximum acceleration of 75 cm/sec^2 (0.075 g) at its center of oscillation. At the roof level of this rectangular structure (roughly one-third higher than its center of oscillation) this could be increased by one-third, making it 100 cm/sec^2, or 0.1 g. This is identical with the acceleration of 0.1 g shown on the penthouse accelerograph record. This agreement, it should be noted, was obtained, not by using the acceleration record obtained in the basement of the building, but simply by using the intensity obtained from descriptive reports collected in the Hollywood area.

While it can be argued that the absolute motion registered by the penthouse accelerograph is the algebraic sum of the ground motion plus the oscillator motion relative to the ground (thus implying that this apparent agreement might be fictitious), it so happens that when a state of sustained resonance exists, as in this case where resonance is obvious, the maximum absolute displacement occurs at the instant when the ground displacement is zero because of the 90° difference in phase between ground and oscillator motion, so that the absolute displacement is virtually the same as the displacement of the oscillator relative to the ground. This same reasoning also applies to the accelerations, since acceleration and displacement reach maximum values simultaneously.

The effective lateral acceleration is at all times the maximum algebraic difference between the absolute acceleration of the center of oscillation of the building and the ground acceleration. If it were desired to determine these accelerations (lateral forces) for cases other than resonance, it would be necessary, first, to estimate the absolute motion of the center of oscillation of the structure from the acceleration registered on the top floor or elsewhere, and then to compute the algebraic differences between this acceleration and that registered on the ground. Although the U.S. Coast and Geodetic Survey has provided simultaneous time marks on instruments operating at different levels in the same building, these time controls have very seldom been employed for this purpose. Such studies could reveal important information regarding the type of oscillation a building experiences during an earthquake. Evidence relating to harmonic vibrations would be of particular interest.

Returning to the Hollywood Storage Building response in the 1933 earthquake, it should be noted that the period in the north-south direction was too long (1.20 sec) to synchronize with any period present in the basement record and consequently there was little amplification at the roof level.

From an inspection of the period-acceleration envelopes and earthquake spectra available it is conceivable that any structure may experience a maximum lateral force due to a resonant ground period at some time or other in its history, but generally the absence of this critical ground period results in relatively little stress on a structure. The only logical way to resolve such a problem is to determine the period pattern by research, possibly from past earthquake records or from special ground observations at the building site. If such studies revealed the absence of the building period in any kind of ground disturbance, the maximum lateral force that the structure might otherwise experience would be definitely lowered. Thousands of buildings have come within this category, at least for shocks occurring

(Continued on page 24)

A SIMPLE METHOD OF APPLYING ELECTRIC STRAIN GAGES TO CONCRETE REINFORCING BARS

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IN CONNECTION WITH RESEARCH on the ultimate strength of certain concrete beams with compression reinforcement,[1] stress measurements on the reinforcing steel and the concrete were desired. Reliable strain readings can be taken from the compression fibers of beam specimens by means of such mechanical strain gages as the Whittemore gage and these strain readings can be converted to stress with the cylinder stress-strain curve. It is also possible to expose a portion of the tension steel in areas of pure bending and by mechanical means determine strains and, therefore, stresses. However, any method which requires exposing the bar is not acceptable for use on compression reinforcement because the area of concrete working in compression is affected and because the decreased lateral restraint may allow premature buckling. Such a method is also undesirable for use on tension reinforcement in areas subjected to shear stress, because of bond requirements. Therefore, consideration was given to the use of Electric Resistance Strain Gages applied to the imbedded reinforcing bar.

A review of the literature showed that this type of instrumentation had been previously used[2,3,4] but these applications were complicated, requiring rather highly skilled personnel. All of the installations discussed were intended for use in measuring long-time stress changes in the steel due to concrete shrinkage and creep or actual field stresses in structures. In the projected tests the entire testing procedure was expected to require about 30 minutes to failure of the beam, and during this period the load would be returned to zero several times. It was therefore believed that these less exacting requirements would make possible a much simpler system of gage protection and waterproofing.

G. G. Goble

After considerable experimentation, the following method of gage application and protection was accepted as the best compromise between simplicity and accuracy of results.

1. The deformations were filed from the bar over an area large enough to accommodate the gage, as shown in Fig. 1 (1). To avoid affecting the working area of the bar, care was taken to remove the deformations no deeper than was necessary to provide a smooth surface.

2. The gage was applied in the manner specified for paper gages using Duco cement. If a type of gage having a felt cover was used, the application of the gage to the curved surface of the bar was simplified by first removing the cover. The gage was allowed to cure a minimum of 48 hours, and if possible much longer. This factor was found to be of paramount importance in the application presented here.

3. The gage was sprayed with two coats of Krylon Spray Coating, a commercial electrical waterproofing compound, and allowed to dry.

4. The entire gage was covered with a heavy coat of vaseline.

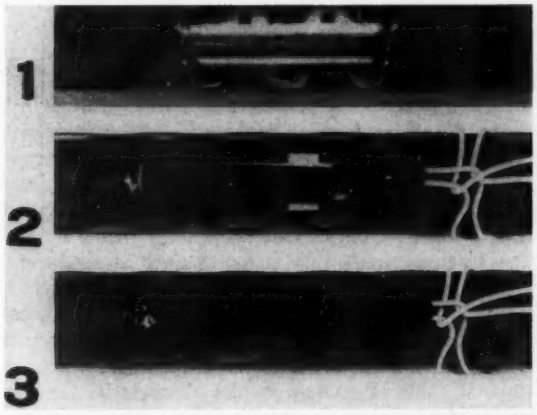

FIG. 1. APPLICATION OF SR-4 GAGE TO DEFORMED BAR

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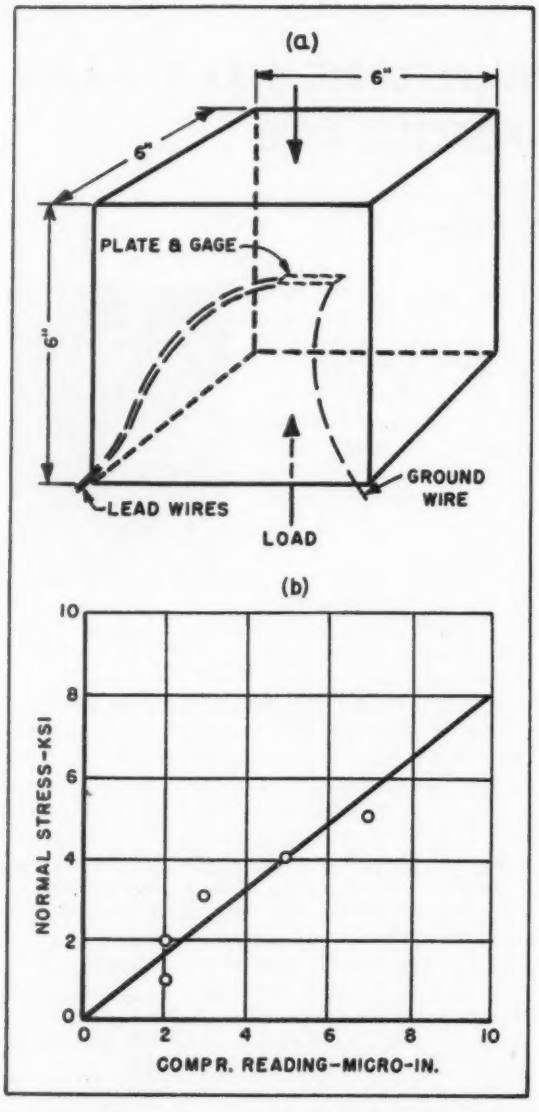

FIG. 2. EFFECT OF NORMAL FORCE ON GAGE READING
(a) Diagram showing method of loading. (b) Compressive readings with increasing normal stress.

5. The felt cover was replaced as shown in Fig. 1 (2), and a piece of very soft brass wire was used to secure it. The bare lead wires were protected with plastic friction tape.

6. The entire assembly was given two coats of TEN-X, a commercial preparation for waterproofing automobile windshields. Best results were obtained when the first layer was applied the day before casting the beam, and the second coat just prior to placing the steel in the forms. The final appearance was as shown in Fig. 1 (3). TEN-X is a soft plastic material which, in addition to excluding all moisture, does not fully harden, thus preventing any interaction between the surrounding concrete and the gage.

A good measure of the effectiveness of the waterproofing material is to check the resistance between the bar and the gage. For good long-term readings this resistance should be at least 100 megohms, but for rapid loading in the measurement of superimposed stresses it can be much less. The method described, when used with reasonable care, will give resistances of at least 0.1 megohm, which produced good results in these tests.

As shown in Fig. 1 (1), some of the bar was filed away to provide a smooth surface on which to apply the gage. It was feared that this decrease in area might be large enough to affect the yield load or the strain-load curve of the bar. Therefore, a number of bars, with and without the deformations removed, were tested in tension. No consistent difference was noted in the yield loads. Consideration was given to removing the deformations in a lathe and turning the bar to a known diameter. However, because of the irregular surface presented by the deformed bar, centering it in a lathe proved to be a time-consuming process for a machinist, and the method was therefore abandoned. Since the hand removal of the deformations over a small area did not affect the yield load of the bar and was, in addition, quickly and easily accomplished, it is the recommended method.

The effect of concrete shrinkage in the plane of the cross section of the beam is to apply a compressive force normal to the plane of the SR-4 gage. The effect of this force on the gage readings is questionable. Some tests for this effect have been run,[4] but they failed to yield conclusive results. In connection with this investigation one test was attempted to determine if forces of the magnitude possible in concrete shrinkage would have an appreciable value. A gage was applied to a small steel plate in the manner described above. The plate was ⅛ in. thick and just larger than the gage. The portion of the plate not covered by waterproofing was given a very thick coat of heavy grease to prevent all bonding between the plate and the concrete. This plate was then placed in a known orientation in a 6-in. cube of concrete. After being cured in the same manner as the beams were cured, the specimen was loaded in the direction normal to the plane of the gage (Fig. 2-a). Compressive strains were recorded with increasing normal stress, as shown in Fig. 2-b. The magnitudes are definitely small enough to be disregarded in the range of normal stress and for the degree of accuracy required for concrete research.

A troublesome problem connected with the use of SR-4 gages was finding a simple and effective method of compensating for temperature changes. Compensator gages could have been mounted normal to the direction of stress near each active gage, but this would have doubled the quantity of gages required, increased the volume of concrete displaced by waterproofing, and greatly increased the cost and time consumed in performing the tests. The following method gave relatively little zero drift, and, when used with care, gave consistent results.

A dummy compensator gage was mounted on a piece of steel and simply placed on the test specimen in an area not interfering with other apparatus. The dummy and the beam were wrapped together with glass-wool insulating material. The test setup was made the day before testing to allow the gages embedded in the beam and the compensator to reach room temperature. Even with these precautions the compensator proved to be more sensitive to temperature changes than the active gages, and therefore every effort was made to keep the room temperature constant during testing and to complete testing as rapidly as possible after zeroing the gages.

As a general check on the accuracy of the electric gages one of the tension reinforcing bars was exposed to permit strain readings with a Whittemore gage. The strain readings taken from the Whittemore and the SR-4 gage mounted on the same bar were compared. A representative sample of these comparisons is shown in Fig. 3. The results from the two methods compare within 5 per cent or less, and the readings from the SR-4 gages were generally more consistent.

As mentioned before, strain readings were desired on the concrete in the compression zone of the beam. These measurements were made using SR-4 gages applied in a manner that has become routine at the University of Washington and, although somewhat simpler, is similar to methods used elsewhere.[5] The specimen was allowed to dry at least three days before testing. After 24 hours the surface was cleaned with a wire brush and a layer of SR-4 cement was applied, filling any small holes. After drying for 24 hours, any roughness was removed with steel wool and a gage was applied over the hardened cement in the normal fashion. Successful readings were taken from these gages with only 24 hours curing time. Temperature compensation can be accomplished by means of a dummy gage applied to a piece of inactive concrete.

In the course of these tests type A-11 and A-7 gages were used. For use on reinforcing bars the smaller A-7 gage proved somewhat easier to apply and waterproof, but for determining concrete strains it gave definitely faulty results. Owing to the

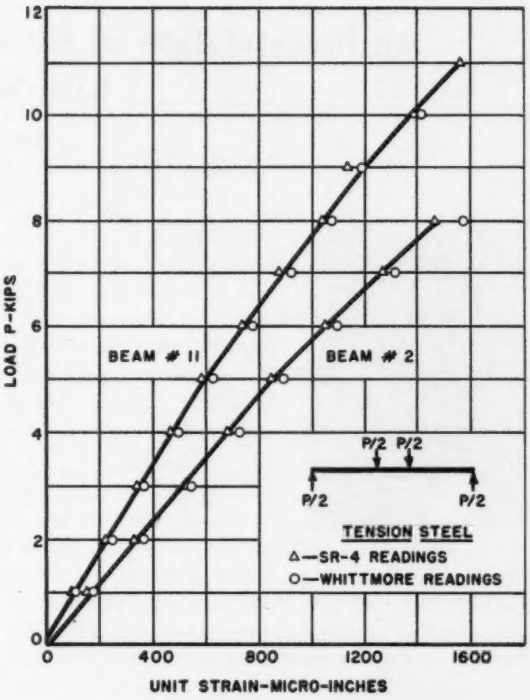

FIG. 3. COMPARISON OF STRAIN READINGS FROM MECHANICAL AND ELECTRICAL GAGES ON ONE BAR OF TENSION STEEL

nonhomogeneous nature of concrete, strain readings must be taken over a long enough gage length to give an average value. Readings over such a short length as afforded by the A-7 gage can be affected by individual rocks in the concrete and will produce unreliable results. The readings of concrete strain obtained from the A-11 gages produced results which, when converted to forces and checked statically across the section, satisfied equilibrium requirements. Thus, if readings on reinforcement only are required, a relatively short gage as the A-7 is to be recommended, but if strain measurements on both concrete and steel are desired, the longer A-11 gage has the advantage of giving satisfactory readings on both materials with one gage type and, hence, requiring only one indicator.

In tests to ultimate load of concrete beams with high percentages of tension steel it is usually difficult to determine if failure began by yielding of the steel or failure of the compression concrete. If yielding takes place in the steel, a "hinge" is formed about the top fibers of concrete and further deflection occurs at no increase in load. Owing to the rotation of the "hinge" the depth of concrete acting in compression is decreased until finally concrete failure destroys the

(Continued on page 23)

An Investigation of Flow Through an Open Channel with Screen Bed

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L-S. Miao

A variation of a basic nonuniform open-channel flow problem was encountered in the study of a migrant-fish facility.[1] For the purposes of that study a porous channel bottom was altered to procure the same discharge rate per lineal foot throughout the length of the channel. A natural corollary to that flow situation is to maintain the same porosity of channel bottom and then investigate the discharge rate through the channel bed as a function of distance from the start of the porous bed.

For the experimental phase of the study, a channel was built with a screen bottom and instrumented so that the discharge through the bottom could be measured over small increments of screen length for different screen slopes and initial flow rates.

For a rectangular flume of width, b, a volume of water bounded by two sections a distance, dx, apart is shown in Fig. 1. In order to obtain a relatively simple equation, the following assumptions are made:

1. The flow is considered to be unidirectional; the lateral unevenness of the water surface, as a result of cross currents, is to be neglected.

2. The velocity in the direction of the flow is uniformly distributed across each section.

3. The slope of the channel is small so that (a) the vertical and normal depths at a section are practically equal, (b) a hydrostatic pressure distribution exists throughout the depth of flow, and (c) no air entrainment occurs.

4. The bottom frictional stress, τ_0, is to be neglected.

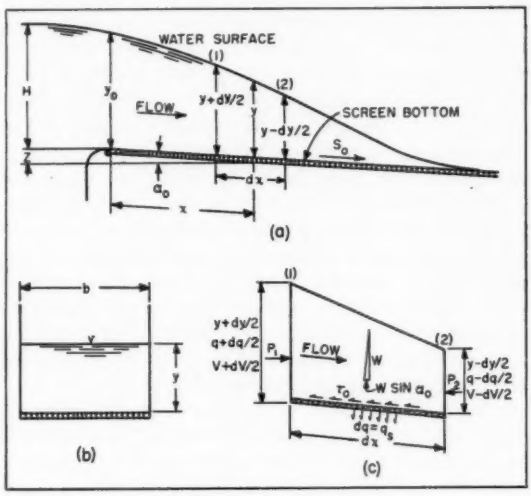

FIG. 1. DEFINITION SKETCHES FOR WATER FLOW THROUGH A FLUME

(a) Longitudinal section (b) Cross section (c) Free body diagram

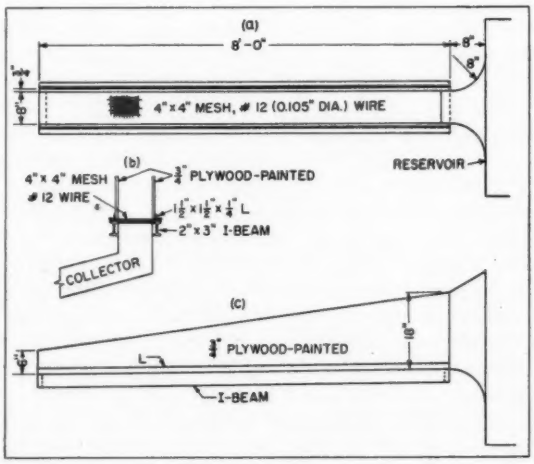

FIG. 2. SCHEMATIC MODEL LAYOUT

(a) Plan (b) Cross section (c) Longitudinal section

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* Mr. Miao is now a senior engineer with Harza Engineering Company, Chicago, Illinois. This article is based upon his thesis for the degree of M.S. in Civil Engineering, 1957.

[1] See "A Model Study of Some Fish Facilities for the Proposed Mayfield Dam; Part I; The Skimmer," by E. P. Richey, *The Trend in Engineering*, Vol. IX, No. 1 (Jan., 1957).

5. For the small values of bottom slope considered, the direction of the velocity vector through the screen is perpendicular to the flow in the channel so that the final momentum in the x-direction of the water passing through the screen is negligible.

By applying the impulse-momentum relations to the control volume of Fig. 1 and eliminating the velocity terms by substitutions from the Energy Equation, the desired differential equation of the water-surface profile was obtained as

$$\frac{dy}{dx} = \frac{(4/k_s^1)\sqrt{(H+z-y)y} - S_0 y}{2(H+z)-y}, \qquad (1a)$$

or $$S = \frac{L - S_0 y}{M}, \qquad (1b)$$

where

S = water-surface profile with respect to bottom; positive for downward,
S_0 = channel bed slope; positive for downward,
H = inlet head,
z = datum elevation,
y = water depth in channel,
$L = (4/k_s^1)\sqrt{(H+z-y)y}$,
$M = 2(H+z)-y$.

The pressure drop, i.e., the energy loss through the screen, is evaluated by the pressure-drop coefficient, or screen-loss coefficient, k_s, defined[1] by

$$k_s = \frac{\Delta p}{\frac{\rho V_s^2}{2}} = \frac{h_L}{\frac{V_s^2}{2g}}, \qquad (2)$$

where

p = pressure difference,
ρ = density of water,
h_L = head loss in screen test,
V_s = velocity of flow through screen hole,
g = gravitational acceleration.

Apparatus and Experimental Results

All the investigations were conducted in an open channel with a bottom made of 4-by-4 mesh No. 12 wire (0.105 in. in diameter). (See Fig. 2a.) The flume was 8 ft long, 18 in. deep at the inlet end and 6 in. at the outlet end; the initial width of 12 in. was reduced to 8 in. to increase the available head in the reservoir. A rounded intake was connected to the entrance of the flume; water was supplied from a constant-head reservoir. The flow rate through the screen, q_s, was determined by a collector to divert the water to a weigh tank.

[1] B. B. Schubauer, W. G. Spangenbery, and P. S. Klebanoff, "Aerodynamic Characteristics of Damping Screen," *National Advisory Committee for Aeronautics Technical Note 2001* (National Bureau of Standards, Washington, D.C., January, 1950).

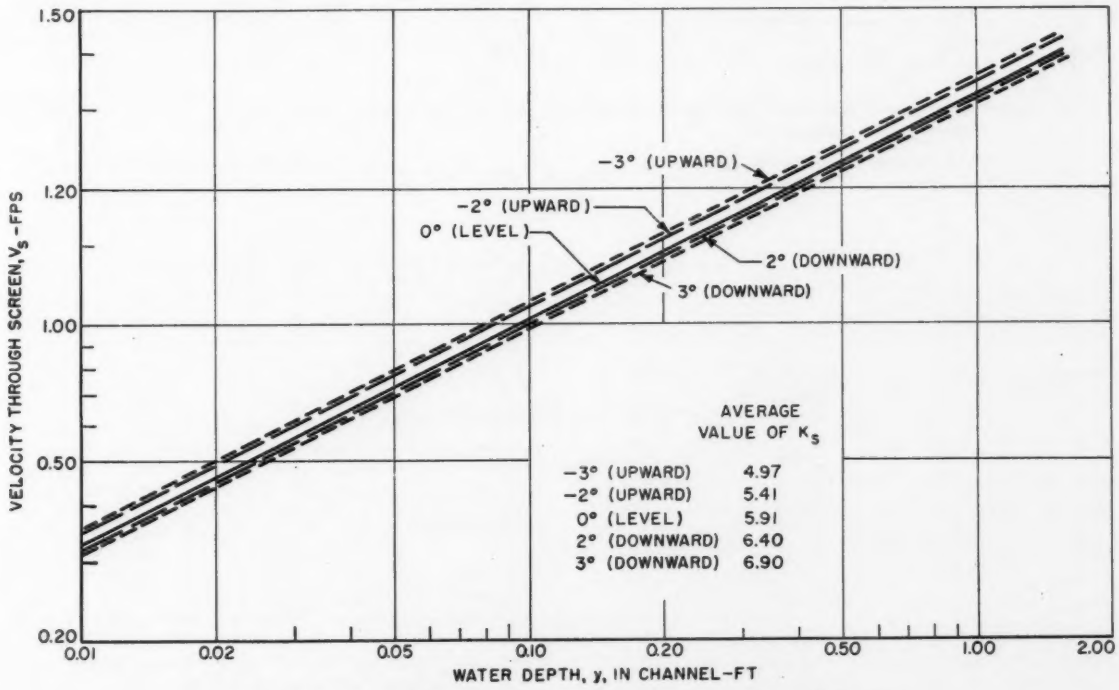

FIG. 3. CURVES OF VELOCITY THROUGH SCREEN VS. DEPTH IN CHANNEL

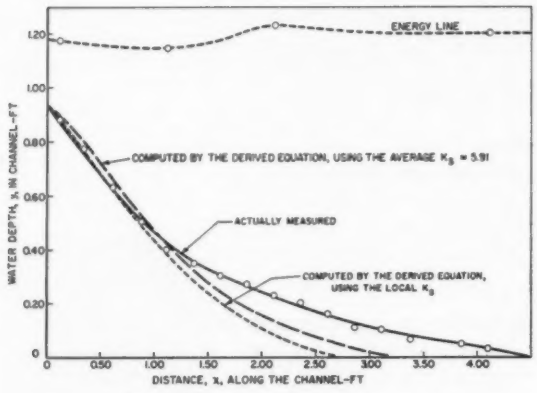
ENERGY LINE
COMPUTED BY THE DERIVED EQUATION, USING THE AVERAGE K_s = 5.91
ACTUALLY MEASURED
COMPUTED BY THE DERIVED EQUATION, USING THE LOCAL K_s
WATER DEPTH, y, IN CHANNEL-FT
DISTANCE, x, ALONG THE CHANNEL-FT

FIG. 4. WATER SURFACE PROFILE
$H = 1.30$ ft; $\alpha_0 = 0°$ (level)

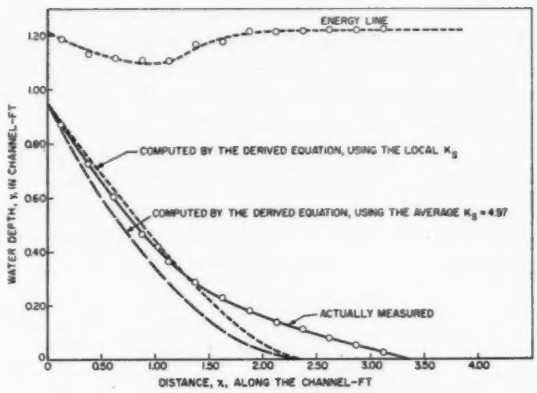
ENERGY LINE
COMPUTED BY THE DERIVED EQUATION, USING THE LOCAL K_s
COMPUTED BY THE DERIVED EQUATION, USING THE AVERAGE K_s = 4.97
ACTUALLY MEASURED
WATER DEPTH, y, IN CHANNEL-FT
DISTANCE, x, ALONG THE CHANNEL-FT

FIG. 5. WATER SURFACE PROFILE
$H = 1.30$ ft; $\alpha_0 = -3°$ (upward)

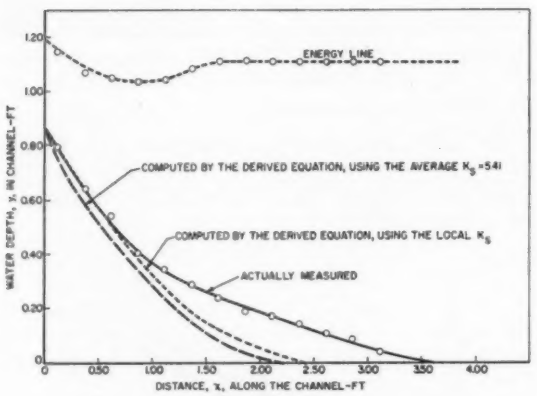
ENERGY LINE
COMPUTED BY THE DERIVED EQUATION, USING THE AVERAGE K_s = 5.41
COMPUTED BY THE DERIVED EQUATION, USING THE LOCAL K_s
ACTUALLY MEASURED
WATER DEPTH, y, IN CHANNEL-FT
DISTANCE, x, ALONG THE CHANNEL-FT

FIG. 6. WATER SURFACE PROFILE
$H = 1.20$ ft; $\alpha_0 = -2°$ (upward)

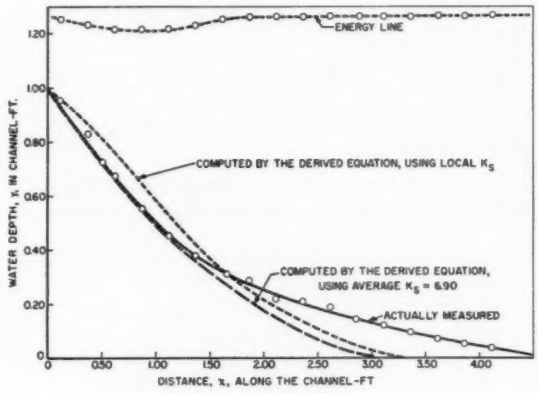
ENERGY LINE
COMPUTED BY THE DERIVED EQUATION, USING LOCAL K_s
COMPUTED BY THE DERIVED EQUATION, USING AVERAGE K_s = 6.90
ACTUALLY MEASURED
WATER DEPTH, y, IN CHANNEL-FT.
DISTANCE, x, ALONG THE CHANNEL-FT

FIG. 7. WATER SURFACE PROFILE
$H = 1.30$ ft; $\alpha_0 = 3°$ (downward)

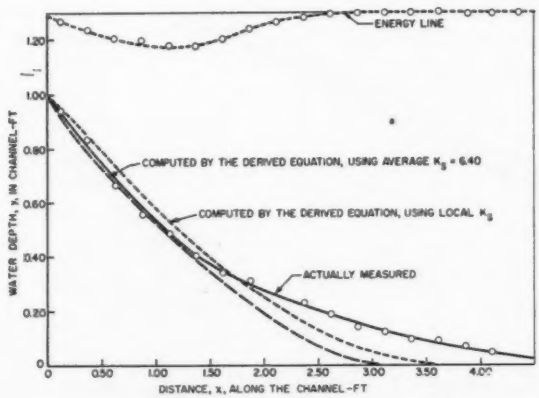
ENERGY LINE
COMPUTED BY THE DERIVED EQUATION, USING AVERAGE K_s = 6.40
COMPUTED BY THE DERIVED EQUATION, USING LOCAL K_s
ACTUALLY MEASURED
WATER DEPTH, y, IN CHANNEL-FT
DISTANCE, x, ALONG THE CHANNEL-FT

FIG. 8. WATER SURFACE PROFILE
$H = 1.35$ ft; $\alpha_0 = 2°$ (downward)

The collector was set under the screen bed and moved in successive increments of 0.25 ft along the I-beams supporting the channel. The velocity parallel to the bed was measured with a pitot-tube; the flume was pivoted so that its slope could be varied to cover the desired experimental range.

An experimental investigation was carried out to study the energy loss through the screen by determining the pressure-drop coefficient and to measure the actual depths in order to furnish an experimental verification of the theoretical analysis (Figs. 3,4,5,6,7, and 8). The responses of the several channel bed slopes were computed, using a step method to solve the derived equation, and were compared with the measured values. Very good correlation was found between the analytical and experimental results.

Results and Conclusions

1. When the depth of water is less than 0.20 ft, the discrepancy between the computed and measured water-surface profiles may be due to the fluctuation of (1) the velocity,[1] (2) the water surface, and (3) the effect of viscosity. The screen-loss coefficient then becomes a function of the water depth.

2. The plotted energy line offers proof that the friction-loss term does not appear in the derived equation of the water-surface profile. Apparently the turbulent eddies formed at the screen boundary are drawn through the channel bottom as rapidly as they are formed. No attempt was made to change the screen porosity to determine at what value the friction effects would begin to influence the profile. The concave portion of the energy line at the start of the channel, where the streamlines are sharply curved, is a result of having measured only the velocity component parallel to the channel bed rather than the total velocity vector.

3. The variation of q_s with distance down the screen is proportional to the square root of the depth, y.

4. For the small bottom slopes studied, the vertical projection of the open area of the screen is nearly zero; the jets through the screen openings are nearly vertical. Therefore it is believed that no serious error was introduced by neglecting the normal component of velocity in determining the pressure-drop coefficient.

5. The computed water-surface profiles agree quite well with the measured ones except when the depth drops below about 0.2 ft.

This study provides a first approximation in the design of a screen with porous bottom. Further refinements would require similar studies varying the screen velocity and considering the effect of the angle of incidence on the screen-loss coefficient.

[1] For the mathematical treatment of the average process of turbulent flow, see J. Kampe de Feriet: "Sur un problème d'Algèbre abstraite pose par la definition de la moyenne dans la théorie de la turbulence," *Annales de la Soc. Sci. de Bruzelles,* Serie I, T. LXIII, 1949, p. 165.

ACKNOWLEDGMENT

The writer wishes to express his thanks to Dr. E. P. Richey, Associate Professor of Civil Engineering, for his valuable assistance in preparing this article.

WHAT PRICE CREATIVITY?

(Continued from page 2)

It is education's business to recognize and encourage him in his most critical years. Wholeness of vision, for example, can be acquired to a certain degree. Dr. J. Bronowski, mathematician and topologist, recently stated: "A man becomes creative, whether he is an artist or a scientist, when he finds a new unity in the variety of nature."[16] Perhaps interests and talents outside of his own field, especially in the arts, contribute to this perspective. Dr. Bronowski, for instance, has written a book on William Blake. Einstein was one of many famous scientists who have had an affinity for music.

Many of our scientific and technological geniuses, we find, have been educated in England or on the continent. Is this significant? Has their traditional education in the humanities helped them to gain perspective?

Can we achieve both universal "group adjustment" and creativity, which, to some extent, will always be "odd man out"? If not, to what degree are we prepared to sacrifice either?

Our culture is still young. Let us hope that it does not succumb to premature hardening of the conformities.

REFERENCES

1. Pierce, J. R., "Innovation in Technology," *Sci. Am.*, Sept., 1958.
2. Osborn, Alex, *Applied Imagination*, New York, Scribner, 1953.
3. Ribot, T., *The Creative Imagination, Chicago*, Open Court, 1906.
4. Lanczos, Cornelius, "Albert Einstein: His Life and His Work," unpublished lectures, Dublin Institute for Advanced Studies, 1955-56.
5. Kroll, William J., "The Lone Wolf Researcher," address given on receiving the Perkin Award, New York, Jan. 10, 1958.
6. Ludovici, L. J., *Fleming: Discoverer of Penicillin*, London, A. Dakers, 1952.
7. Wiener, Norbert, *I am a Mathematician*, Garden City, N.Y., Doubleday, 1956.
8. Compton, Arthur H., *Atomic Quest*, New York, Oxford Uni. Press, 1956.
9. Lincoln, John W., "Lone Invention—No Lost Art," *Prod. Engg.*, June 2, 1958.
10. Jewkes, J., Sawers D., Stillerman, R., *The Sources of Invention*, London, Macmillan & Co., Ltd., 1958.
11. Taylor, Donald W., "Does Group Participation When Using Brainstorming Facilitate or Inhibit Creative Thinking?" ONR Study.
12. Nelles, M., "Deliberate Creativeness in Science and Engineering," *Chem. Bull.*, Feb., 1953.
13. Ohmann, O. A., "The Innovator," *Chem. Engg. Prog.*, April, 1957.
14. Lodge, R. M., "Economic Factors in Planning Research," Nov., 1954, quoted in Reference 10.
15. Bernal, J. D., *Science and Industry in the 19th Century*, London, Routledge & K Paul, 1953.
16. Bronowski, J., "The Creative Process," *Sci. Am.*, Sept., 1958.

A MICROWAVE FIELD DETECTOR*

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The techniques for the measurement and detection of microwave power have undergone little change since World War II. With a few exceptions, such progress as has been made in this field since that time has been in the direction of the refinement of the existing techniques which have been, by and large, quite satisfactory.

In recent years, however, certain shortcomings in these techniques have become apparent. The use of the conventional calorimetric and bolometric devices for power measurement, because of the inherent thermal inertia involved, are not entirely satisfactory for the measurement of pulsed microwave power. This is particularly true when the duration of the pulse is but a small fraction of the repetition cycle. Consequently, considerable effort is currently being expended in the development of techniques for the instantaneous measurement of microwave power.[1]

In the case of the detection problem, the germanium crystal, because of its low noise level and extreme sensitivity, has been eminently satisfactory as a detector. However, recent advances in the development of oscillators operating at millimeter wavelengths have forced the crystal detector into a region where its sensitivity is seriously impaired. This loss of sensitivity at extremely high frequencies is caused by a small capacitance which exists between the point contact and the surface of the crystal.

This work describes a new technique for the detection of microwave power. Briefly, the technique involves the absorption of microwave energy by a gas, resulting in ionization of the gas atoms. Since a known amount of energy is required for each ionization, the amount of energy absorbed by the process can be determined by counting the number of ions produced. Ions, being charged particles, are easily counted by sweeping them out of the gas by means of an electric field and measuring the resultant current. Thus if a gas absorbs energy by ionization, the conductivity of the gas is increased. This change in conductivity provides a means of detecting microwave energy.

A. E. Harrison

The problem involved in constructing a detector based on this principle is to induce the gas to absorb microwave energy. Since the energy of the photon associated with microwave radiation has a magnitude very much less than that required to ionize gas atoms directly, a photoelectric interaction is impossible. However, it has been shown[2] that gases may absorb microwave energy by an indirect process if free electrons are present in the gas. In this process, the free electrons are set into oscillatory motion by the electric field of the radiation and ionize the gas atoms by collision. Thus we have a two-stage process: the radiant energy is absorbed by the free electrons as they are accelerated into oscillatory motion; the energy is then given up to the gas atoms upon collision. This process has been described in detail by S. C. Brown.[3,4]

In order to ionize a gas atom by collision, an electron must have a kinetic energy which is greater than the ionization potential of that atom. The maximum kinetic energy due to oscillatory motion of an electron oscillating under the influence of an alternating electric field is a function of the amplitude of the electric field. It would seem, therefore, in the process described above, that there would be some amplitude of the electric field below which ionization of any given atom would be impossible. Surprisingly, this is not the case. In general, the velocity of oscillation of an electron in the presence of an alternating electric field is superimposed on some initial random velocity. Once the electron is oscillating under the influence of an alternating electric field, the oscillating component of its velocity is, in the steady state, in phase quadrature with the electric field and, if we neglect radiation damping, the electron takes no power, on the average, from the field. If, however, the electron suffers an elastic (non-ionizing) collision with a gas atom, this phase relation is destroyed.

* Condensed from the thesis of T. G. Williams submitted as partial requirement for the degree of M.S. in Electrical Engineering, 1958.

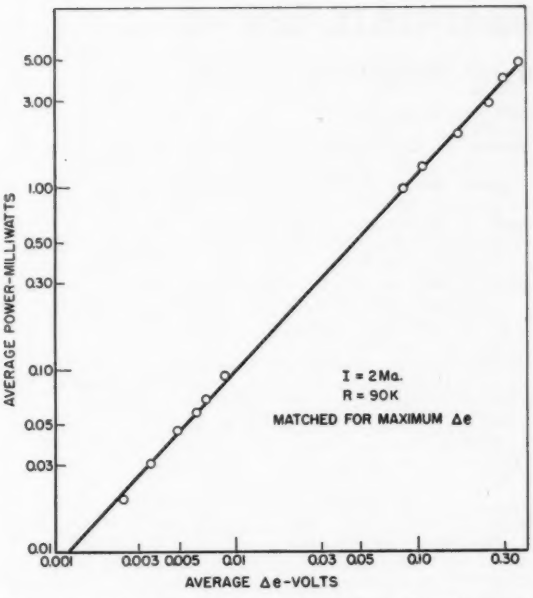

FIG. 1. POWER ABSORPTION CHARACTERISTIC WITH TUBE MATCHED FOR MAXIMUM Δe

The electron is then either accelerated or decelerated by the field as the quadrature phase relation is restored. If the electron is accelerated as a result of such an event, a net gain in kinetic energy results. Thus on each elastic collision the electron will either gain or lose kinetic energy. By a fortuitous sequence of collisions an electron can gain sufficient energy to effect an ionizing collision even at very small values of the applied alternating field. During the course of the present work this effect was observed at microwave frequencies down to a power level of ten microwatts. There was no evidence of a lower limit to the process. The investigation was stopped at ten microwatts only because of noise level and not because of any deterioration of the ionizing process.

The possibility of using this technique for the detection of microwave energy was recognized during the course of some experimental work in connection with the development of a power-measuring technique, when it was observed that the current through a glow discharge increased appreciably in the presence of microwave radiation. An investigation of the phenomenon showed that the effect was the result of the interaction of the microwave energy with the free electrons provided by the glow discharge which acted on an electron source.

Surprisingly enough, a simple neon glow-tube makes a rather good microwave detector. If a resistor is connected in series with the glow-tube and the discharge is exposed to microwave radiation, the

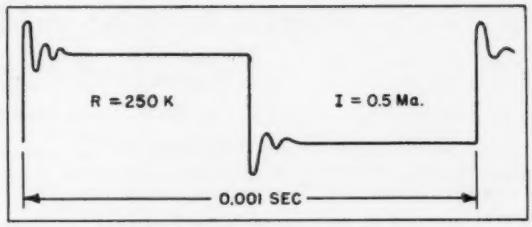

FIG. 2. TYPICAL WAVEFORM SHOWING UNDESIRABLE TRANSIENT RESPONSE

voltage across the tube will decrease. The change in voltage across the tube is approximately proportional to the microwave power absorbed over a range of power from 10 microwatts to 100 milliwatts. The power absorbed as a function of the voltage increment is shown in Fig. 1.

Unfortunately, because of the dynamic characteristics of the glow discharge, the glow-tube detector has a rather undesirable transient response. A typical undesirable wave form is shown in Fig. 2 for square wave modulated power. Furthermore, at microwave frequencies, the glow-tube detector is less sensitive than the crystal detector by a factor of about ten. Hence it is doubtful that this simple device will have significant practical application. The principle upon which its operation depends, however, promises some interesting possibilities.

One whch seems particularly worthy of investigation is based on a thermionic source of electrons. If a gas-filled diode is operated at a plate voltage less than the first excitation potential of the gas, the gas will not affect conduction and the current will be limited by the space charge effect. If microwave energy were to be propagated through the interelectrode space, since free electrons are present, energy will be absorbed by the gas atoms and ionization will result. The products of ionization will contribute directly to the current through the tube as they do in the glow-tube detector. In this case, however, the presence of the positive ions in the interelectrode region will tend to neutralize the space charge and increase the current through the tube by an additional amount. This space charge neutralization technique has long been used as an ion detector, and the production of 10^3 to 10^4 electrons for each ion introduced has been reported.[5] Thus by the use of such a technique one might expect to improve the sensitivity of detection several orders of magnitude over that observed in the glow-tube detector. During the course of this investigation crude devices using electron sources were operated successfully but no measurements were made.

It seems possible that this technique can be applied to the power measurement problem, although here

(Continued on page 25)

PUBLICATIONS AND GRADUATE THESES

College of Engineering 1957-1958

(EES: Engineering Experiment Station Assistant)

AERONAUTICAL ENGINEERING

Dill, Ellis H., "Vibration of Rectangular Plates and Plate Systems," Third U.S. Nat. Congress App. Mech., 1958.

M.S. in Aeronautical Engineering

CHAHINE, M. T., The Uses of Real Gases in a Shock Tube (1957). (EES)

FANNELOP, T. J., Design of a Hypersonic Shocktube (1957). (EES)

GREGORY, R. A., The Profile of Weak Shock Waves from Maxwell's Kinetic Theory (1958).

KRESSNER, W. K-H., Reinforced Plastics as a Structural Material for Aircraft and Missiles (1957).

MCCLURE, J. D., Dynamic Loads and Stability Analyses for High Speed Aircraft (1958).

MORGAN, W. B., Design Considerations for a Hypersonic Wind Tunnel (1957). (EES)

MORRIS, R. C., A Preliminary Design Investigation of Hypersonic Wind Tunnels (1957). (EES)

NAGEL, A. L., A Method for Calculation of the Aerodynamic Heating of a Symmetrical Body (1958).

M.S. in Engineering

COLTON, E., The Study of Aerodynamic Sound (1958).

CHEMICAL ENGINEERING

Anderson, D. K., "Mutual Diffusion in Non-Ideal Binary Liquid Mixtures" **(with A. L. Babb, J. R. Hall),** *Jour. Phys. Chem.,* Vol. 18, No. 4 (April, 1958). EES Reprint No. 142.

Babb, Albert L., "Mutual Diffusion in Non-Ideal Binary Liquid Mixtures" **(with D. K. Anderson, J. R. Hall),** *Jour. Phys. Chem.* Vol. 18, No. 4 (April, 1958). EES Reprint No. 142.

———, "Kinetic Studies of Carbonation Reactions Using Radioactive Tracers" **(with D. M. Himmelblau),** *Amer. Inst. Chem. Engr. Jour.,* Vol. 4, No. 2 (June, 1958). EES Reprint No. 144.

———, "Graphite-Natural Uranium Subcritical Reactor Systems for Education and Research" **(with W. E. Wilson, L. Grimsrud),** *Proceed.,* 2nd Internat. Conf. on Peaceful Uses of Atomic Energy, in press, Sept., 1958.

———, "Nuclear Engineering at the University of Washington" **(with R. W. Moulton),** *Puget Sound Engr.,* Vol. XII, No. 6 (1957).

Back, E., "Absorbance Corrections for Finite Slit Width with Non-Uniform Absorbants" **(with V. F. Felicetta, J. L. McCarthy).** *Anal. Chem.,* in press.

———, "Lignin XI: Estimation of Polymolecularity in Lignin Sulfonate Polymers from Diffusion Measurements" **(with J. Moacin, H. Nelson, V. F. Felicetta, J. L. McCarthy)** *Jour. Am. Chem. Soc.,* accepted for publication.

Felicetta, V. F., "The Pulp Mills Research Program at the University of Washington" **(with J. L. McCarthy),** *TAPPI Magazine,* Vol. 40, 851-66 (1957). EES Reprint No. 128.

———, "Absorbance Corrections for Finite Slit Width with Non-Uniform Absorbants" **(with E. Back, J. L. McCarthy),** *Anal. Chem.,* in press.

———, "Lignin X: Moment Relationship Derivation for the Distribution of Diffusion Coefficients in Polymers" **(with J. Moacin, J. L. McCarthy),** *Jour. Am. Chem. Soc.,* accepted for publication.

———, "Lignin XI: Estimation of Polymolecularity in Lignin Sulfonate Polymers from Diffusion Measurements" **(with J. Moacin, H. Nelson, E. Back, J. L. McCarthy),** *Jour. Am. Chem. Soc.,* accepted for publication.

Grimsrud, L., "Graphite-Natural Uranium Subcritical Reactor Systems for Education and Research" **(with A. L. Babb, W. E. Wilson),** *Proceed.,* 2nd Internat. Conf. on Peaceful Uses of Atomic Energy, in press, Sept., 1958.

Hall, J. R., "Mutual Diffusion in Non-Ideal Binary Liquid Mixtures" **(with D. K. Anderson, A. L. Babb),** *Jour. Phys. Chem.,* Vol. 18, No. 4 (April, 1958). EES Reprint No. 142.

Himmelblau, D. M., "Kinetic Studies of Carbonation Reactions Using Radioactive Tracers" **(with A. L. Babb),** *Amer. Inst. Chem. Engr. Jour.,* Vol. 4, No. 2 (June, 1958). EES Reprint No. 144.

Johanson, L. N., "Adsorption Kinetics in the Conversion of Carbon Dioxide to Methane" **(with J. B. Romero),** *The Trend in Engineering,* Vol. 10, No. 2 (April, 1958).

———, "Characteristics of Gas Pockets in Fluidized Beds" **(with G. Yasui),** *AIChE Jour.,* accepted for publication.

McCarthy, Joseph L., "The Lignin Problem," *Ind. Engr. Chem.,* Vol. 49, 1377 (1957).

———, "The Pulp Mills Research Program at the University of Washington" **(with V. F. Felicetta),** *TAPPI Magazine,* Vol. 40, 851-66 (1957). EES Reprint No. 128.

———, "Absorbance Corrections for Finite Slit Width with Non-Uniform Absorbants" **(with E. Back, V. F. Felicetta),** *Anal. Chem.,* in press.

———, "New Horizons in the Pulp and Paper Industry," *Western Conservation Jour.,* Vol. 14, No. 16 (1957).

———, "Lignin X: Moment Relationship Derivation for the Distribution of Diffusion Coefficients in Polymers **(with J. Moacin, V. F. Felicetta),** *Jour. Am. Chem.* Soc., accepted for publication.

———, "Lignin XI: Estimation of Polymolecularity in Lignin Sulfonate Polymers from Diffusion Measurements" **(with J. Moacin, E. Back, V. F. Telicetta, J L. McCarthy),** *Jour. Am. Chem. Soc.,* accepted for publication.

Moacin, J., "Lignin X: Moment Relationship Derivation for the Distribution of Diffusion Coefficients in Polymers" **(with V. F. Felicetta, J. L. McCarthy),** *Jour. Am. Chem. Soc.,* accepted for publication.

———, "Lignin XI: Estimation of Polymolecularity in Lignin Sulfonate Polymers from Diffusion Measurements" **(with H. Nelson, E. Back, V. F. Felicetta, J. L. McCarthy),** *Jour. Am. Chem. Soc.,* accepted for publication.

Moulton, R. W., "Nuclear Engineering at the University of Washington" **(with A. L. Babb),** *Puget Sound Engr.,* Vol. XII, No. 6 (1957).

Nelson, H., "Lignin XI: Estimation of Polymolecularity in Lignin Sulfonate Polymers from Diffusion Measurements" **(with J. Moacin, E. Back, V. F. Felicetta, J. L. McCarthy),** *Jour. Am. Chem. Soc.,* accepted for publication.

Romero, Jacob B., "Adsorption Kinetics in the Conversion of Carbon Dioxide to Methane" **(with L. N. Johanson),** *The Trend in Engineering,* Vol. 10, No. 2 (April, 1958).

Wilson, W. E., "Graphite-Natural Uranium Subcritical Reactor Systems for Education and Research" **(with A. L. Babb, L. Grimsrud),** *Proceed.,* 2nd Internat. Conf. on Peaceful Uses of Atomic Energy, in press, Sept., 1958.

Yasui, G., "Characteristics of Gas Bubbles in Fluidized Beds" **(with L. N. Johanson),** *AIChE Jour.,* accepted for publication.

Ph.D. in Chemical Engineering

BOLME, D. W., Adsorption and the Catalytic Oxidation of Ethylene (1957).

HIMMELBLAU, D. M., Kinetic Studies in the System: Carbon Dioxide-Hydrogen Sulfide-Sodium Bicarbonate-Sodium Sulfide-Water (1957).

M.S. in Chemical Engineering

ANDERSON, D. K., Self and Mutual Diffusion in Non-Ideal Liquid Systems (1958).

BABCOCK, L. R., JR., Vapor Phase Association in the System Ethyl Acetate, Ethyl Alcohol, Acetic Acid, and Water (1958).

NELSON, H. K., The Application of a Digital Computer to the Calculation of the Diffusion Coefficient Distribution of Lignins by the Method of Moments (1957).

ORGEN, D. E., Gas to Particle Heat Transfer in a Fluidized Bed (1957).

PEAK, R. F., Capital and Operating Costs of Cation Exchange Units and Methods of Cation Exchange Bed Design (1957). (EES)

ROSS, K. E., Continuous Column Separations of the Molecular Sieve Type (1958).

M.S. in Engineering (Nuclear)

LAWRENCE, D. C., Fast Neutron Dosimetry of a Plutonium-Beryllium Source (1958).

WRIGHT, D. E., A Radioactive Tracer Technique to Determine the Distribution of Residual Air in a Honeycomb Panel (1958).

CIVIL ENGINEERING

Beano, S. Y., "Effects of Fabrication Techniques on Bolted Joints" **(with D. D. Vasarhelyi, R. B. Madison, Z-A. Lu, U. C. Vasishth)** *ASCE Proceed., Jour. Struct. Div.,* accepted for publication.

Bogan, R. H., "Sewage Treatment by Lagoons," *ASCE Proceed., Jour. San. Engg. Div.,* Res. Rep. No. 18, Vol. 84-SA3 (June, 1958).

———, "Biochemical Degradation Products and Stream Pollution," *Chem. Process.,* Sept., 1957.

———, "Biochemical Degradation By-Products: A New Form of Water Pollution?" *The Trend in Engineering,* Vol. 10, No. 1 (Jan., 1958).

Chauner, Richard W., "Does Vibration Affect Friction in a Bolted Joint?" **(with D. D. Vasarhelyi),** *The Trend in Engineering,* Vol. 9, No. 4 (Oct., 1957).

Ekse, Martin, "Exemptions and Diversions from Motor Vehicle Licensing and Taxation" **(with R. H. Myers),** Highway Economic Studies, Dec., 1957.

———, "The Value of Soil Test Data in Local and Regional Road Planning," *Proceed., ASTM,* Vol. 58 (1958). EES Reprint No. 143.

Goble, G. G., "A Simple Method for Applying SR-4 Gages to Concrete Reinforcing Bars," *The Trend in Engineering,* Vol. 10, No. 4 (Oct., 1958).

Hawkins, Sidney E., "An Appraisal of Methods for Improvement of Slope Stability" **(with R. G. Hennes, E. L. McCoy),** *Bull.,* Highway Research Board, 1958.

Hennes, Robert G., "Highway Benefit Analysis," *Jour. Engg. Ed.,* Vol. 48, No. 5 (Feb., 1958). EES Reprint No. 132.

———, "An Appraisal of Methods for Improvement of Slope Stability" **(with S. E. Hawkins, E. L. McCoy),** *Bull.,* Highway Research Board, 1958.

———, "Subgrade Frost Action and Related Soil Properties" **(with G. Yamane),** *The Trend in Engineering,* Vol. 9, No. 4 (Oct., 1957).

Horwood, Edgar M., "The Federal Interstate Highway Program and the City Center," *Proceed.,* NW Conf. on Road Building, Uni. of Wash., 1958.

———, "Towards a New Rationale for the Planning of Urban Highways," *Ibid.,* Oregon State College, 1957.

———, "City Center Goods Movement," *Bull.,* Highway Research Board, 1958.

Lu, Z-A., "Effects of Fabrication Techniques on Bolted Joints" **(with D. D. Vasarhelyi, S. Y. Beano, R. B. Madison, U. C. Vasishth),** *ASCE Proceed., Jour. Struct. Div.,* accepted for publication.

Madison, R. B., "Effects of Fabrication Techniques on Bolted Joints" **(with D. D. Vasarhelyi, S. Y. Beano, Z-A. Lu, U. C. Vasishth),** *ASCE Proceed., Jour Struct. Div.,* accepted for publication.

McCoy, Eugene L., "An Appraisal of Methods for Improvement of Slope Stability" **(with R. G. Hennes, S. E. Hawkins),** *Bull.,* Highway Research Board, 1958.

Miao, L-S., "An Investigation of Flow Through an Open Channel with Screen Bed," *The Trend in Engineering,* Vol. 10, No. 4 (Oct., 1958).

Miller, Alfred L., "Wood Diaphragms: Progress Report of Sub-Committee" (Chairman), *ASCE Proceed., Jour. Struct. Div.,* Paper 1433, ST 6, Nov., 1957.

———, "Warping of Reinforced Concrete Due to Shrinkage," *Jour. Amer. Concrete Inst.,* Vol. 29, No. 11 (May, 1958). EES Reprint No. 140.

Okey, R. W., "The Green-Duwamish River: A Resource Study" **(with R. O. Sylvester),** *The Trend in Engineering* Vol. 9, No. 4 (Oct., 1957).

Sergev, S., Discussion of "Buckling of Struts on a Thin Plate" by J. L. Cutliffe and H. S. Heaps, *Jour. Appl. Mech.,* Vol. 24, No. 4 (Dec., 1957).

Sylvester, R. O. "Some Influences of Multi-Purpose Water Usage on Water Quality," *Internat. Union for the Conservation of Nature and Natural Resources,* Sept., 1958.

———, "The Green-Duwamish River: A Resource Study" **(with R. W. Okey),** *The Trend in Engineering,* Vol. 9, No. 4 (Oct., 1957).

Vasarhelyi, D. D., "Does Vibration Affect Friction in a Bolted Joint?" **(with R. W. Chauner),** *The Trend in Engineering,* Vol. 9, No. 4 (Oct., 1957).

———, "Effects of Fabrication Techniques on Bolted Joints" **(with S. Y. Beano, R. B. Madison, Z-A. Lu, U. C. Vasishth),** *ASCE Proceed., Jour. Struct. Div.,* accepted for publication.

Vasishth, U. C., "Effects of Fabrication Techniques on Bolted Joints" **(with D. D. Vasarhelyi, S. Y. Beano, Z-A. Lu, R. B. Madison),** *ASCE Proceed., Jour. Struct. Div.,* accepted for publication.

Yamane, G., "Subgrade Frost Action and Related Soil Properties" **(with R. G. Hennes),** *The Trend in Engineering,* Vol. 9, No. 4 (Oct., 1957).

M.S. in Civil Engineering

ADAIR, F. E., A Laboratory Study of Settlement Involving Both Consolidation and Plastic Flow (1958).

ALBERTSON, O. E., Development of a Tertiary Algal Treatment Process (1957). (EES)

CHU, T. K., An Investigation of Discharge Coefficient of Multiple Orifices (1958). (EES

ELWESS, R. L., Determination of the Flexural Strength of Compacted Bituminous Mixes (1958).

HANSEN, G. H., A Study of the Composting of Municipal Refuse (1958). EES

HOYT, K. D., Feasibility Studies for Proposed River and Harbor Model Laboratory (1957). (EES)

HUANG, D. T-N., Investigation of Flexural Strength of Compacted Bituminous Paving Slabs with Steel Wire Mesh Reinforcement (1958).

LONG, R. W., The Role of the Triaxial Compression Test in Flexible Pavement Design (1958).

PNEUMAN, F. C., Elastic Instability of Kinked Axes Columns (1958).

SIDDIQUI, S. H., Minor Losses in Viscous Flow (1958). (EES)

WU, H-S., The Formation of Plastic Hinges at Low Temperature (1958).

M.S. in Engineering

BEANO, S. Y., The Effect of Various Treatments of the Faying Surface and of the Misalignment of Holes on the Coefficient of Friction and Efficiency of Bolted Joints (1958).

DOSSOU, G., Prestressing Applied to Structural Steel by Use of High Tensile Strength Steel Cables (1958).

SCHULER, D. A., Experimental Determination of Strains in Reinforcing Steel as Induced by Concrete Shrinkage (1958).

ELECTRICAL ENGINEERING

Clark, R. N., "Compensation of Steady State Flow Forces in Hydraulic Valves," *ASME Trans.*, Nov. 1957.

———, *Fundamentals of Automatic Control,* accepted for publication by John Wiley & Sons.

Dobrott, D., "Lunar Tidal Variations in the Height of Ionospheric Layers" **(with H. M. Swarm, R. Nagata)** *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

Guy, A. W., "A Broadband Dual-Mode Transducer" **(with G. Held),** *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

Harrison, A. E., "A Microwave Field Detector" **(with T. G. Williams),** *The Trend in Engineering,* Vol. 10, No. 4 (Oct., 1958).

———, "Photogrammetry of Glaciers," *IRE Student Quart.*, Vol. 4, No. 1 (Sept., 1957).

Held, G., "A Broadband Dual-Mode Transducer" **(with A. W. Guy),** *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

———, Radiation Pattern Synthesis with Sources Located on a Conical Surface" **(with A. Ishimaru),** *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

Hoard, G. L., "Injurious and Lethal Effects of Electricity on Young Salmon" **(with L. A. Verhouven),** *Tech. Rep.* No. 19, School of Fisheries, Univ. of Wash., 1957.

———, "Effects of Water Conductivity and Electrode Geometry on the Shock Received by Fish in an Electrical Field," *Tech. Rep.* No. 24, School of Fisheries, University of Washington, 1957.

Ishimaru, A., "Radiation Pattern Synthesis with Sources Located on a Conical Surface" **(with G. Held),** *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

Johnson, D. L., "Logical Processing and Context Analysis in Mechanical Translation" **(with R. E. Wall),** *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

Lewis, L. G., "The Solution of Large Networks by Sectionalizing," *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

Nagata, R., "Lunar Tidal Variations in the Height of Ionospheric Layers" **(with H. M. Swarm, D. Dobrott),** *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

Smith, G. S., "Residential Heating: Electric vs. Gas or Oil," *AIEE* Trans., Paper No. 58-1012, 1958. EES Rep. No. 138.

Swarm, H. M., "Lunar Tidal Variations in the Height of Ionospheric Layers" **(with D. Dobrott, R. Nagata),** *The Trend in Engineering,* Vol. 10, No. 3 (July, 1958).

Wall, R. E., "Logical Processing and Context Analysis in Mechanical Translation" **(with D. L. Johnson),** *The Trend in Engineering,* Vol. 10, No. 3, (July, 1958).

Ph.D. in Electrical Engineering

ISHIMARU, A., Radiation Pattern Synthesis with Sources Located on a Conical Surface (1958).

M.S. in Electrical Engineering

ASHBAUGH, F. E., Artificial Anisotropic Dielectrics and Their Application to Elliptically Polarized Omnidirectional Antennas (1957).

DE GROOT, E. B., A Superheterodyne System for Cross-Modulation Measurements on Low-Power Traveling-Wave Tubes (1958). (EES)

HILL, R. V., A Radial Surface Wave Antenna (1958). (EES)

MAESHIRO, A., A Study of Carrier Current Transmission Through a Faulted Power Transmision Line (1958).

NATION, A. W. C., A Cross-Modulation Technique for Microwave Amplifiers (1957).

SAUGEN, J. L., A Study of Digitally Controlled Systems by Analog Computer Simulation (1958).

TASHIRO, S., A Study of Flux Distribution and Reactivity for a Spherical Intermediate Reactor Employing an Iterative Technique for Solving Diffusion Equations (1958).

WILLIAMS, T. G., A Microwave Phototube (1958).

M.S. in Engineering

QUIRK, W. J., Fields in a Conical Cavity Resonator (1958).

GENERAL ENGINEERING

Boehmer, H., *Fundamentals of the Slide Rule,* Uni. of Wash. Education and Extension Services, Sept., 1957.

Dunn, W. L., "Landfill Gas Burned for Odor Control," *Civ. Engg.*, Vol. 27, p. 792 (Nov., 1957).

HUMANISTIC-SOCIAL STUDIES

Elliott, E. C., "Perspectives of Linguistic Science" **(with A. G. Julliand),** *Report of the Seventh Annual Round Table Meeting on Linguisitics and Language Study,* Institute of Languages and Linguistics, Georgetown Uni., Dec., 1957.

———, "On the Understanding of Color in Painting," *Jour. Aesth. and Art Crit.*, Vol. XVI, No. 4 (June, 1958).

Souther, J. W., *Technical Report Writing,* John Wiley & Sons, Inc., New York, Nov., 1957.

———, "Cooperation Between Universities and Industry in the Training of Technical Writers and Editors," *Proceed. Soc. Tech. Writers and Editors,* Nov., 1957.

MECHANICAL ENGINEERING

Anderson, J. W., "Effects of Thermal Upsetting in 5052 Aluminum Alloy" **(with R. E. Holt, E. C. Roberts),** *The Trend in Engineering,* Vol. 10, No. 1 (Jan., 1958).

Balise, P. L., "Coriolis Acceleration: The General Case," *Jour. Engg. Ed.*, Vol. 48, No. 5 (Feb., 1958). EES Reprint No. 130.

———, "Have You Written Your Paper Yet?" **(with W. H. Crater, M. D. Blickle),** *Ibid.* EES Reprint No. 131.

Day, E. E., "Recent Laboratory Evaluation of High-Temperature Strain Gages to 900° F," *Proceed.*, High Temperature Symposium, 1958. EES Reprint No. 139.

———, "New Techniques in Photoelasticity" **(with J. Holen),** *The Trend in Engineering,* Vol. 10, No. 2 (April, 1958).

Hendrickson, H. M., "Conventional Freezing Cycles and Economics for Saline Water Conversion," *Refrig. Engg.*, Aug., 1958.

———, "Air Conditioning Calculations," Chap. 14, *ASRE Data Book: Design,* 10th ed., 1957-58.

———, "Fishing Boats," Chap. 36, *ASRE Data Book: Applications,* 7th ed., 1959, accepted for publication.

———, "Conventional Freezing Cycles and Economics for Saline Water Conversion," *Proceed.*, Symposium on Saline Water Conversion, 1957, NAS-NRC Pub. 568, 1958.

Holen, J., "New Techniques in Photelasticity" **(with E. E. Day),** *The Trend in Engineering,* Vol. 10, No. 2 (April, 1958).

Holt, R. E., "Effects of Thermal Upsetting in 5052 Aluminum Alloy" **(with E. C. Roberts, J. W. Anderson),** *The Trend in Engineering,* Vol. 10, No. 1, (Jan., 1958).

Mills, B. D., Jr., "The Nelson Slide Rule," *Amer. Math. Monthly,* Vol. LXV, No. 3 (Mar., 1958).

———, "A Checking Device for Strain-Gage Indicators," *ASTM Bull.*, accepted for publication, 1958.

Schaller, G. S., "New Foundry Sand," *Modern Metals,* Oct., 1957.

———, "Industrial Applications of Olivine Aggregate" **(with W. A. Snyder),** *Trans. AFS (Modern Castings),* Vol. 33, No. 6 (June, 1958).

Setchfield, D., "Mechanized CO_2 Molds Stacked to Produce Novelty Castings" **(with L. B. Zylstra),** *Foundry,* Nov., 1958.

Snyder, W. A., "Industrial Applications of Olivine Aggregate" **(with G. S. Schaller),** *Trans. AFS (Modern Castings),* Vol. 33, No. 6 (June, 1958).

Waibler, P. J., "Natural-Convection Heat Transfer with Water at High Grashof Numbers," Abstract accepted for publication, *Theses Abstracts,* Uni. of Illinois.

Zylstra, L. B., "Mechanized CO_2 Molds Stacked to Produce Novelty Castings" **(with D. Setchfield),** *Foundry,* Nov., 1958.

M.S. in Mechanical Engineering

CHENG, Y-F, A Study of Crack Propagation in Sheet Metals (1957). (EES)

COLLICOTT, H. E., Water Vapor Transmission Through Building Materials (1957). (EES)

GOLIAN, T. C. J., Thermodynamic and Gasdynamic Functions of Gases (1958).

JAMIESON, J. J., A Theoretical and Electronic Analog Study of a Hydraulic Servomechanism (1957).

MINTO, R. W., A Mechanical Analog for Second-Order Differential Equations with Constant Coefficients (1957).

ROSS, J. E., A Study of the Design of an Aircraft Hydraulic System (1957).

ROTTER, J. F., A Method for Stress Analysis of a Shaft and Socket Structural Joint (1957).

SEELEY, E. B., The Snap-Action Bimetallic Thermal Disk and Its Application to Thermal Switches (1957). (EES)

STORA, F. X., The Photogrammetric Method of Elevation Determination Applied to the Soap Film Analogy (1957).

M.S. in Engineering

GRIMSRUD, L., A Study of Heat Transfer and Fluid Flow Characteristics for Sulfite Spent Liquor at High Concentrations of Solids (1957). (EES)

KASSEL, H. W., Development of an Automatic Brake Control System (1958).

MINERAL ENGINEERING

Brien, F. B., "Recent Trends in Uranium Extraction," *AIMM Bull.*, Vol. 9, No. 9, (Sept., 1957).

———, "Uranium Extraction," *Mining Mag.*, Inst. Min. & Metal. (London), Vol. XCVII, No. 4 (Oct., 1957).

———, "Uranium Mining at Rayrock Mines," *Milling of Canadian Ores*, Can. Inst. Min. & Metal. Press, Nov., 1957.

———, "Modern Mineral Dressing," Bull., Puget Sound Engineering Council, Jan., 1958.

Daniels, J., "Analysis of Washington Coals: Supplement to Tech. Papers 491 and 619" **(with H. F. Yancey, M. R. Geer, et al),** U. S. Bureau of Mines, 1958.

Roberts, E. C., "The Present Status of Stainless Steels," *Scrap Age-Waste Age*, Aug., 1957.

———, "Effects of Thermal Upsetting in 5052 Aluminum Alloy" **(with R. E. Holt, J. W. Anderson),** *The Trend in Engineering*, Vol. 10, No. 1 (Jan., 1958).

———, "A Kinetic Study of a Solid-State Reaction," *The Trend in Engineering*, Vol. 10, No. 2 (April, 1958).

———, "The Effect of Manganese on the Curie Point of Cementite," *Trans. ASM*, Vol. 50 (1958). EES Reprint No. 137.

M.S. in Ceramic Engineering

BRESLICH, F. N., The Effect of Minor Additives in the Sintering of Alumina (1958).

KAMDAR, M. H., Quantitative Determination of Glassy Phase in High Alumina Bodies (1957). (EES)

M.S. in Ceramics

CARTER, G. J., A Steatite Body Composed of Raw Materials of the Northwest (1957).

HODSON, J. E., Dental Ceramics (1958).

M.S. in Metallurgical Engineering

ANDERSON, W. E., Rate-Controlling Factors in the Annealing of Polycrystalline Aluminum (1957).

LLOYD, R. H., X-Ray Spectroscopic Analysis of Copper in a Lead Bullion and PbO_2 Slag (1957).

M.S. in Metallurgy

PAULSON, D. L., Plastic Parameters for Metals from a New General Equation Relating Stress and Strain (1958).

MS. in Mining Engineering

CORP, E. L., Screening Performance of the DSM Sieve Bend (1958).

JOHNSON, P. H., Drainage and Rinsing of Magnetite Medium from Fine Coal (1957).

LOWE, E. A., Flotation of Chromite from Olivine (1958).

Applying Electric Strain Gages To Concrete Reinforcing Bars

(Continued from page 13)

beam. With low reinforcement percentages a large decrease of effective compression area is necessary before beam destruction occurs, allowing large deflections at constant load. Hence, this type of failure can readily be attributed to steel yielding. However, for large steel percentages concrete failure can occur only an instant after the beginning of yield in the steel. This type of failure will likely be attributed to concrete yielding. The rapid operation possible with SR-4 gages permits the operator to monitor several gages during loading (at near ultimate load) and thus locate the first point of yielding, determining without question the type of failure.

Since this technique was developed primarily for simplicity, accuracy was sometimes forfeited and readings of a long-time nature are impossible. However, for short-time readings SR-4 gages offer considerable advantage over mechanical gages. They give greater accuracy, they can be read and the readings "doubled" more easily and with less training, and they can be read much more rapidly, with a corresponding saving in manpower.

REFERENCES

1. GOBLE, G. G., "Investigation of Doubly Reinforced Concrete Beams to Verify the Ultimate Theory," unpublished Master's Thesis, University of Washington, 1957.
2. SHERLOCK, R. H., and BELGIN, A., "Protection of Electric Strain Gages in Concrete," *ACI Journal*, Vol. 19 (Nov., 1947), p. 189.
3. HOGNESTAD, E., and VIEST, I. M., "Some Applications of Electric SR-4 Gages in Reinforced Concrete Research," *Ibid.*, Vol. 21 (Feb., 1950), p. 442.
4. PERRY, C. C., and LISSNER, H. R., *The Strain Gage Primer*, New York, McGraw-Hill Book Company, Inc., 1955, p. 281.
5. COOKE, R. W., and SEDDON, A. E., "The Laboratory Use of Bonded-Wire Electrical Resistance Strain Gages on Concrete at the Building Station," *Magazine of Concrete Research*, Vol. 8, No. 22 (March, 1956).

Oscillator Responses to Earthquake Motions

(Continued from page 10)

within historic time. Thousands of old and poorly designed structures survive relatively strong shocks for this reason. The formula here proposed, however, provides only for the worst condition that can be reasonably expected.

When one examines on the provisional quantitative intensity grid all of the intensities and periods associated with an acceleration of 0.1 g and reflects on the fact that structures designed to withstand this static acceleration have generally come through strong shocks with little or no damage, there seems reason to believe that the real function of the 0.1-g provision in building codes is primarily to eliminate any outstanding weakness that may exist in the design of a structure. Once this is done, the evidence indicates that thousands of well-designed and well-built structures will actually withstand lateral forces that are many times 0.1 g. It would seem, therefore, that the primary function of the proposed formula is to show in quantitative terms the relative effects of building period and damping on lateral forces rather than to set definite lateral force limits at which a structure may be expected to fail or not to fail. From this viewpoint the proposed formula is primarily a tool that may aid the engineer to exercise good judgment along more logical lines than heretofore.

Conclusions

The writer hopes that this proposed solution of a problem basically seismological will give impetus to further research in the earthquake engineering field. The question of how to correlate the responses of dozens of multiperiod oscillators with dozens of different types of earthquake motion is a formidable one, and an approach along the lines here outlined has been long overdue. The analogy between mechanical oscillator responses and geological oscillator responses to earthquake forces seems highly significant, especially so if we have a tool in the form of an intensity grid whereby it becomes possible to evaluate these responses quantitatively in terms of intensity which every engineer understands. It is hoped that study of the intensity grid and its various ramifications can be continued.

This paper goes beyond the concept of a quantitative intensity grid as developed in the writer's booklet, *Earthquake Intensity and Related Ground Motion*, and introduces Crandell's concept that intensity is primarily a function of vibrational velocity instead of a complex logarithmic function that is not greatly different from a velocity function over the limited band of frequencies thus far studied. Further study of this aspect of the grid is obviously needed.

Some critics have asked in recent years: What direct and specific use is being made of the seismological data thus far collected in designing earthquake-resistant structures? This paper illustrates very clearly how both instrumental and noninstrumental information collected in the field can be molded into a tool that will enable the engineer to determine lateral forces on structures by a relatively simple procedure, once certain observational facts are established. But it is obvious that the problem as a whole is a complex one and there are still hurdles to be overcome before the proposed procedure can be considered 100 per cent operational.

Recommendations

The most urgent needs as seen by the writer are as follows:

1. The evaluation of earthquake intensity in terms of the periods and amplitudes of recorded ground vibrations (the intensity grid) needs to be further investigated and developed. The provisional grid published by the writer in 1954 does not cover the range of frequencies desired by the engineer, some obvious deviations related to epicentral distance and regional structure require clarification, and the purely empirical grid as developed to date needs to be correlated with certain basic theoretical concepts of energy distribution in order to be wholly acceptable. This adds up to a prodigious task that lies definitely in the field of seismological research. The ultimate results would very likely be applicable to other disciplines involving forced vibrations of a complex character.

2. Studies of damping in various types of buildings need to be accelerated so that ultimately a good estimate of damping can be made simply by knowing the more important structural characteristics of a building.

3. The writer reported in 1954 that intensity and ground-motion studies showed that under certain favorable conditions there could be as much as 22 times more motion on soft ground than on adjoining outcrops of basement rock. Studies should therefore be made of individual sites to determine what amplifications might be expected in severe earthquakes. There is also the period problem. If certain ground periods are found to be dominant and others are totally absent, that knowledge would govern to a large extent the earthquake stresses to be expected in structures erected on the sites. Feasible methods

of determining these ground characteristics need to be developed through adequate research programs.

4. Greater use should be made of seismograph records obtained at various levels in buildings to study the character of building deformations and to test the validity of formulas, such as the one proposed here, that are designed to predict earthquake stresses.

5. Engineers should make more model tests designed to show how theoretical forces on oscillators can be translated into equivalent forces on geometrically complex buildings and other engineering structures.

6. Since vibrational velocity seems to be a reliable function of intensity, a simple type of maximum velocity indicator should be designed and installed in seismic areas. It would require no time scale. The data when analyzed on an intensity grid would indicate the period-acceleration combinations that would yield the observed velocity. If a building were assumed to be virtually in a state of resonance, the building period would be known (if not previously or ultimately measured), and the maximum acceleration and displacement could be deduced. The primary purpose of the indicator, however, would be to serve as an intensity meter.

BIBLIOGRAPHY

ALFORD, J. L., HOUSNER, G. W., and MARTEL, R. R., *Spectrum Analysis of Strong-Motion Earthquakes*, Earthquake Research Laboratory, California Institute of Technology, 1951.

CRANDELL, F. J., "Ground Vibration Due to Blasting and Its Effect Upon Structures," *Jour. Boston Soc. Civ. Engrs.*, Vol. 36, No. 2 (April, 1949), pp. 222-245.

HOUSNER, G. W., *Intensity of Ground Motion During Strong Earthquakes*, Earthquake Res. Lab., C.I.T., 1951.

HUDSON, D. E., "Response Spectrum Techniques in Engineering Seismology," *Trans. World Conference on Earthquake Engineering*, Dept. of Engg., University Extension, University of California, Berkeley, June, 1956.

NEUMANN, FRANK, "Damaging Earthquake and Blast Vibrations," *The Trend in Engineering*, Jan., 1958, University of Washington Engineering Experiment Station.

———, *Earthquake Intensity and Related Ground Motion*, University of Washington Press, 1954.

U.S. Coast and Geodetic Survey, "Earthquake Investigations in California, 1934-35," G.P.O. Special Publication 201, 1936.

U.S. Coast and Geodetic Survey, *United States Earthquakes* (series), Annual reports. G.P.O.

WHITE, MERIT P., "Friction in Buildings: Its Magnitude and Its Importance in Limiting Earthquake Stresses," *Bull. Seis. Soc. Amer.*, Vol. 31 (April, 1941), p. 93.

WOOD, H. O., and NEUMANN, F., "Modified Mercalli Intensity Scale of 1931," *Bull. Seis. Soc. Amer.*, Vol. 21 (Dec., 1931), p. 277.

A Microwave Field Detector

(Continued from page 19)

the technical difficulties are somewhat more formidable. One difficulty is that a gas absorbs energy by two processes. In one, the absorption of energy may result in the change of energy level of an electron within the atom. This energy is subsequently reradiated by the atom when the electron returns to its normal state. In the second process the electron is completely removed from the atom with the production of a positive ion and a free electron. It is only the second process, ionization, which affects the conductivity of the gas. Hence it is necessary to eliminate or control the first process if we are to measure all of the power absorbed by measuring the change in conductivity of the gas. A second difficulty is that we must introduce the required free electrons in such a manner that the conductivity of the gas will be independent of the voltage of the measuring electrodes. That is, space charge effects and ionization by the measuring voltage must be avoided. A third difficulty is the possibility of recombination of the ions produced by the absorption process. This effect may possibly be reduced to negligible proportions by the proper choice of electrode geometry.

The gaseous absorption technique described above is an effective method for detecting high-frequency electromagnetic radiation. The principal advantage of this technique is the volumetric nature of the interaction. Since the mechanism upon which operation depends takes place on an atomic scale, no shunt capacitances are involved to limit operation at high frequencies. It therefore seems probable that detectors based on this principle can be designed to operate with considerable sensitivity at the highest frequencies obtainable with macroscopic oscillators. In addition, the use of space charge neutralization techniques promises sensitivities which are equal to or better than the sensitivity obtainable with conventional methods.

REFERENCES

1. THOMAS, H. A., "Microwave Power Measurements Employing Electron Beam Techniques," *Proceed. of the IRE*, Vol. 45, Feb., 1957, pp. 205-11.
2. HERLIN, M. A., and BROWN, S. C., "Breakdown of a Gas at Microwave Frequency," *Phys. Rev.*, Vol. 75, Aug., 1948, p. 291.
3. MCDONALD, A. D., and BROWN, S. C., "High Frequency Gas Discharge Breakdown," *Ibid.*, Feb., 1947, p. 411.
4. BROWN, S. C., "High Frequency Gas Discharge Breakdown," *Proceed. of the IRE*, Vol. 39, Dec., 1951, pp. 1493-1501.
5. LOEB, L. B., *Basic Processes of Gaseous Electronics*, Univ. of Calif. Press, Berkeley, Calif., 1955, pp. 628-34.

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

PNEUMAN, F. C., "Elastic Instability of Kinked Axes Columns." M.S. in Civil Engineering, 1958.

This thesis reports the results of the experimental testing of four columns kinked about their strong axes. The purpose of the tests was to compare the buckling loads of the kinked columns with that of a straight column of like over-all height, cross-sectional area, and end fixity. To obtain a variety of results, four columns with kinked axes and varying ϕ angles (angles between the vertical and the kinked axes) were chosen to be tested. The ϕ angles were chosen arbitrarily as follows: 15°, 22.5°, 30°, and 45°.

The test columns were machined from a ¼-in. plate of 7178-T6 aluminum. The nominal width of all specimens was 2.00 in., and the effective length, i.e. length from support to support, of each column was 21 in. The slenderness ratio for the straight column was 300.

Each column was tested under five different conditions of end fixity: fully fixed, top and base; fixed base with simply supported top; fixed base with knife-edge supported top; knife edges, top and base; and simply supported top and base. Vertical deflections were measured and plotted against the applied load in each case and the buckling load obtained from the resulting graph. Also obtained for most tests were the lateral displacements of the midpoint and quarterpoints of each column. These data showed that a column with a simple support deflects more vertically and less laterally than one with a knife-edge support. The strain in the compressive side of the kink was also measured and the resultant stress computed. The maximum compressive stress developed was 23,100 psi, while the yield point for the 7178-T6 aluminum plate used for the columns was 77,300 psi.

The test results indicated that a kinked axis column, with a ϕ angle near zero, was almost as strong as a straight column under like end fixity. The vertical displacement parallel to the load on a kinked axis column, however, was much greater than that on a straight column even when the initial imperfections were greater in the straight column.

ORGEN, D. E., "Gas to Particle Heat Transfer in a Fluidized Bed." M.S. in Chemical Engineering, 1958.

The original purpose of this work was to increase understanding of gas fluidization by finding the relationship between bypassing bubbles and heat transfer coefficients. Data on bubble size, frequency and rise velocity needed for such a correlation were obtained from Yasui's Ph.D. thesis, University of Washington (1957).[1] Heat transfer was so rapid that thermal equilibrium was attained between gas and solid within one inch above the support screen so that the relation between bypassing bubbles and heat transfer coefficients could not be obtained.

The column used in this work was four inches in diameter with high velocity thermocouples to record the inlet and outlet air temperatures and a device to allow the rapid introduction of solids into the column. Thermal equilibrium between gas and solids was determined by both steady-state and unsteady-state processes. In the unsteady-state method, 93.5 to 337 lb per hr-ft^2 of hot air entered the column through a 200-mesh screen while a given weight of glass beads ranging from 0.5 to 11.3 lb at room temperature was suddenly introduced into the column. Inlet air temperature ranged from 125° F to 304° F and glass bead size from 75 to 242 microns. By recording the temperature of the outlet air versus time, the ratio $hpA/(hpA+wCpg)$ was obtained from equations developed by Wamsley.[2] This ratio was found to be approximately equal to one which indicated thermal equilibrium between gas and solid. This result was verified by comparison of measured solid temperature and outlet air temperature at the termination of a run. In the steady-state measurements, wet alumina (60/100 mesh) was fluidized with air (132 to 156° F and a mass velocity of 335 lb per hr-ft^2). The wet alumina and the air leaving the fluidized bed were both at the adiabatic saturation temperature of water, indicating that equilibrium between the gas and solid had occurred.

[1] "Characteristics of Air Pockets in Fluidized Beds."

[2] W. W. Wamsley, Ph.D. thesis, University of Washington, 1953, "Heat Transfer in Fluidized Beds Effectiveness of Gas-Solid Contact."

SUBJECT INDEX

Volumes 9-10

A

ABSORPTION kinetics in the conversion of carbon dioxide to methane. J. B. Romero, L. N. Johanson. Vol 10 No 2 Apr '58 17

ALGAL TREATMENT. Development of a tertiary a. t. process. (abs) O. E. Albertson. Vol 10 No. 1 Jan '58 22

ALUMINA. Quantitative determination of glassy phase in high a. bodies. (abs) M. H. Kamdar. Vol 10 No 1 Jan '58 22

ALUMINUM ALLOY. Effects of thermal upsetting in a. a. R. E. Holt, E. C. Roberts, J. W. Anderson. Vol 10 No 1 Jan '58 18

ANALOG COMPUTER. *See under* Computers

ANTENNAS. Reduction of side lobes in directional a. (for abs) Vol 9 No 1 Jan '57 28
See also under Radiation pattern

B

BEAMS. *See under* Concrete *and* Prestressed

BOLTED JOINT. Does vibration affect friction in a b. j? R. W. Chauner, D. D. Vasarhelyi. Vol 9 No. 4 Oct '57 23

BOUNDARY LAYER. An approximate solution of Prandtl equation of fluid motion in the b. l. (for abs) Vol 9 No 2 Apr '57 32

BRIDGE. Methods employed for the scaffolding and arch construction for the Montanges B. (for abs) Vol 9 No. 4 Oct '57 29

C

CARBON DIOXIDE. Countercurrent steam stripping of c. d. from soda-lye solutions. F. J. Young, M. M. David. Vol 9 No 1 Jan '57 13
See also under Adsorption

CATION EXCHANGE. *See under* Fixed bed.

CHROMITE. New c. extraction process. Vol 10 No 2 Apr '58 30

CIVIL ENGINEERING at the University of Washington. Vol 9 No 4 Oct '57 2
Graduate studies and research in c. e. 1955-1957 Vol 10 No 4 Oct '57 5

COLUMNS. Elastic instability of kinked axes c. (abs) F. C. Pneuman. Vol 10 No 4 Oct '58 26

COMPUTERS. Application of digital c. in power-system hydro-storage problems. D. L. Johnson. Vol 9 No 2 Apr '58 8
Study of digitally controlled systems by analog c. simulation. (abs) J. L. Saugen. Vol 10 No 3 July '58 34
See also under Mechanical Translation

CONCRETE. A simple method of applying SR-4 gages to c. reinforcing bars. G. G. Goble. Vol 10 No 4 Oct '58 11
Contribution to the study of problems in the utilization of light-weight c. (for abs) Vol 10 No 2 Apr '58 29
Rupture by bending and shearing stress in reinforced c. beams. (for abs) Vol 10 No 2 Apr '58 29
See also under Prestressed

CRACK PROPAGATION in sheet metals. (abs) Y-F. Cheng. Vol 9 No 4 Oct '57 22

CREATIVE POTENTIAL. Recognizing and developing c. p. (rep) John E. Arnold. Vol 9 No 2 Apr '57 1

CREATIVITY. What price c.? (ed) Vol 10 No. 4 Oct. '58 1
No 4 Oct '58 1

CREEP rates on eccentrically loaded test pieces. (for abs) Vol 9 No 4 Oct '57 29

CROTONALDEHYDE. Catalysts containing iron, molybdenum, and vanadium oxides in the vapor phase oxidation of c. to maleic anhydride. (abs) F. J. Shelton. Vol 9 No 1 Jan '57 29

D

DIGITAL COMPUTER. *See under* Computers

E

EARTHQUAKE. Damaging e. and blast vibrations. F. Neumann. Vol 10 No 1 Jan '58 5
Oscillator responses to e. motions. F. Neumann. Vol 10 No 4 Oct '58 5

ELECTRICAL ENGINEERING at the University of Washington. Vol 10 No 3 July '58 2
Graduate studies and research in e. e. 1956-1958. Vol 10 No 3 July '58 5

ENGINEER. The new e. (ed) A. V. Eastman. Vol 10 No 3 July '58 1

ENGINEERING EDUCATION. Aspects of modern e. e. (ed) J. W. Hodgins. Vol 10 No 2 Apr '58 1
See also under Professional ethics

ENGINEERING TEACHING. Consider a career in e. t. (rep) H. E. Wessman. Vol 9 No 2 Apr '57 2

ENGINES. On the heat dissipation of 4-stroke cycle petrol e. (for abs) Vol 9 No 2 Apr '57 32

ETHICS. *See under* Professional ethics

F

FISH FACILITIES. A model study of f. f. for the proposed Mayfield Dam. Part I. The skimmer. E. P. Richey. Vol 9 No 1 Jan '57 5
Part II. Upstream migrant system. E. P. Richey, H. H. Chenoweth. Vol 9 No 2 Apr '57 5

FIXED BED. Process design of f. b. cation-exchange units. M. M. David, R. F. Peak. Vol 9 No 3 July '57 20

FLOW. Investigation of f. through an open channel with screen bed. L-S. Miao. Vol 10 No 4 Oct '58 14
just behind three-dimensional shock. (for abs) Vol 9 No 4 Oct '57 29
Minor losses in viscous f. (abs) S. H. Siddiqui. Vol 10 No 2 Apr '58 25

FOUNDATIONS. Study of shallow f. (for abs) Vol 10 No 1 Jan '58 21

FOURIER SERIES. A simplified method of differentiating and evaluating functions represented by F. s. (rep) A. M. Winslow. Vol 9 No 1 Jan '57 26

FRICTION. *See under* Bolted joint

FROST ACTION. Subgrade f. a. and related soil properties. G. Yamane, R. G. Hennes. Vol 9 No 4 Oct '57 18

G

GLACIER. *See under* Photogrammetry

GRADUATE. The g. meets industry. (ed) Vol 9 No 3 July '57 1
studies and research. *See under* Civil engineering *and* Electrical engineering

GREEN-DUWAMISH RIVER: A resource study. R. W. Okey, R. O. Sylvester. Vol 9 No 4 Oct '7 13

H

HEAT PUMP: its principle, operation, installation, etc. (for abs) Vol 9 No 1 Jan '57 28

HEAT TRANSFER during nucleate boiling of liquids under conditions of natural convection. (for abs) Vol 10 No 2 Apr '58 29

Gas to particle h. t. in a fluidized bed. (abs) D. E. Orgen. Vol 10 No 4 Oct '58 26

HYPERSONIC. *See under* Shock tube

I

IONOSPHERIC LAYERS. Lunar tidal variations in the height of i. l. H. M. Swarm, D. Dobrott, R. Nagata. Vol 10 No 3 July '58 8

L

LAMINAR SKIN FRICTION. Approximate l. s. f. in compressible flows with favorable pressure gradients. E. S. Levinsky. Vol 9 No 2 Apr '57 13

M

MECHANICAL TRANSLATION. Logical processing and context analysis in m. t. D. L. Johnson, R. E. Wall. Vol 10 No 3 July '58 14

Noun phrase analysis using the IBM 650 computer. A. D. Stathacopoulos. Vol 9 No 2 Apr '57 20

METHANE. *See under* Adsorption

MICROWAVE field detector. T. G. Williams, A. E. Harrison. Vol 10 No 4 Oct '58 18

Investigation of the cut-off region for a m. metal-strip artificial dielectric. (abs) T. Y. Otoshi. Vol 10 No 3 July '58 34

MODULUS OF ELASTICITY. Effect of heat treatment on the m.o.e. of clay bodies. (abs) C. H. Wang. Vol 9 No 4 Oct '57 22

N

NETWORK. Solution of large n. by sectionalizing. L. J. Lewis. Vol 10 No 3 July '58 31

NUCLEAR. *See under* Reactor

P

PHOTOELASTICITY. Comparative study by three-dimensional p. of stress distribution on Charpy impact test specimens. (for abs) Vol 9 No 4 Oct '57 29

New techniques in p. J. Holen, E. E. Day. Vol 10 No 2 Apr '58 10

PHOTOGRAMMETRY of glaciers. A. E. Harrison. Vol 9 No 3 July '57 5

POLLUTION. *See under* Water pollution

PRESTRESSED CONCRETE. An aid in the preliminary design of p. c. beams J. R. Clanton. Vol 9 No 2 Apr '57 28

Test on p. continuous slabs. (for abs) Vol 9 No 1 Jan '57 28

PROFESSIONAL ETHICS and engineering education. (ed) A. A. Hemenway. Vol 10 No 1 Jan '58 1

A rejoinder. O. H. Lentz. Vol 10 No 2 Apr '58 2

PUBLICATIONS and graduate theses, College of Engineering:

1956-1957. Vol 9 No 3 July '57 27

1957-1958. Vol 10 No 4 Oct '58 20

R

RADIATION PATTERN synthesis with sources located on a conical surface. A Ishimaru, G. Held. Vol 10 No 3 July '58 23

RADIO PROPAGATION. "Explorer" aids r. p. research. H. M. Swarm. Vol 10 No 2 Apr '58 5

REACTOR. Study of flux distribution and reactivity for a spherical intermediate r. (abs) S. Tashiro. Vol 10 No 2 Apr '58 25

REFUSE DUMP. Settlement and temperature of a covered r. d. W. L. Dunn. Vol 9 No 1 Jan '57 19

ROAD BUILDERS hold eleventh annual meeting. R. G. Hennes. Vol 10 No 2 Apr '58 27

S

SCREENING. *See under* Wet screening

SHOCK TUBE. Design of a hypersonic s. t. (abs) T. K. Fannelop. Vol 10 No 1 Jan '58 22

Use of real gases in a s. t. (abs) M. T. Chahine. Vol 10 No 1 Jan '58 22

SILICA. Industrial silica in the Pacific Northwest. E. E. Mueller. Vol 9 No 1 Jan '57 22

SKIMMER. *See under* Fish facilities

SOIL. Device for measuring the swell pressure of s. B. J. Strom, R. G. Hennes. Vol 9 No 3 July '57 9

See also under Frost action

SOLID-STATE REACTION. Kinetic study of a s-s. r. E. C. Roberts. Vol 10 No 2 Apr '58 6

STEEL at high elastic limit in welded construction (for abs) Vol 10 No 2 Apr '58 29

New electrolytic etchants for stainless s. containing sigma phase. (for abs) Vol 9 No 2 Apr '57 32

STRUCTURAL DAMPING. *See under* Vibration

STRAIN GAGES. *See under* Concrete

SUPERSONIC. Effect of high s. Mach numbers on logitudinal stability derivatives. (abs) J. C. Nielsen. Vol 9 No 4 Oct '54 22

SWEPT PLATES. Deflection and stiffness of s. p. due to in-plane loading. (abs) V. J. Modi. Vol 9 No 4 Oct '57 22

T

TEACH. Who's going to teach them and how? (ed) Vol 9 No 1 Jan '57 1

THERMAL SWITCHES. The snap-action bimettalic thermal disk and its application to t. s. (abs) E. B. Seeley. Vol 10 No 2 Apr '58 25

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V

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W

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See also under Algal treatment

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Z

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